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SURVEYING.

(PART I).

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THIRTEENTH EDITION.

ROORKEE:

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PREFACE TO THE ROORKEE TREATISE ON CIVIL ENGINEERING IN INDIA.

THE Roorkee Treatise was originally compiled by Lieut.-Col. J. G. Medley, R.E., in 1866 and issued in two volumes.

The Treatise grew out of the various College Manuals, dealing for the most part with subjects which required special treatment to suit the climate and methods used in India, and has been constantly revised and re-written. It is found advisable now to publish the Treatise in separate Sections, so that each Section can be written or revised and brought up to date whenever opportunity occurs, to keep pace with modern methods and discoveries.

The Treatise now contains the following Sections :—

Section	I.	Building Materials, ...	1924.
,,	II.	Masonry, ...	1924.
,,	III.	Carpentry, ...	1926.
,,	IV.	Earthwork, ...	1926.
,,	V.	Estimating, ...	1926.
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PREFACE.

In revising this Manual the author has studied the needs of the Civil Engineer in India. He has omitted all reference to archaic and obsolete instruments, descriptions of which will be found in earlier editions.

C. J. VEALE.

CONTENTS.

CHAPTER I.

DRAWING, SCALES, ETC.

Management of Papers, Instruments, etc., used in Plain Drawing.

1. However well a survey may have been done in the field, it will never appear to its fullest advantage on paper, if great care and attention to minutiæ are not bestowed on its delineation. All surveys are essentially composed of details, and the greater the accuracy of the detail, the more valuable the survey. Moreover, as all methods of surveying are based upon geometrical principles, geometrical drawing must play an important part in representing those details. A few hints, therefore, on the management of the instruments, etc., in most common use, will not be out of place here.

2. Drawing Paper.—The paper, of good quality but not too highly glazed, should present as smooth a surface as possible. Anything that tends to destroy the surface, such as erasures, excessive rubbing with india-rubber, washing, etc., should be avoided as much as possible. If india-rubber is necessary, it should be used sparingly, and pressed very lightly on the paper. Bread should be used instead of india-rubber when possible.

For survey work, or any work requiring accuracy, the paper should never be *wetted*, but damped only when stretched or mounted on a drawing board, preferably on the underside on account of the distortion that takes place when the stretched paper is cut off. Unequal expansion or contraction should above all things be guarded against.

If the paper is buckled and requires flattening, the following method should be employed:—Mount the paper as described in the following paragraph. When nearly dry, cut it off the board, and place the sheets flat in a drawer, where they must be allowed to remain for three weeks at least, till they are thoroughly seasoned.

During the time occupied in plotting an extensive survey, the paper which receives the work is affected by the changes which take place in the hygrometrical state of the air and the parts laid down from the same scale, at different times, will not exactly correspond, unless this scale has been first laid down upon the paper itself and all the dimensions have been taken from the scale so laid down.

For plotting an extensive survey, and accurately filling in the minutiæ a diagonal scale may advantageously be laid down upon the paper upon which the drawing is to be made. The construction of scales will be treated of further on.

Drawing Paper, properly so called, is made to certain standard sizes, as follows:—

Demy	20 inches	by	$15\frac{1}{4}$ inches.
Medium	$22\frac{3}{4}$	„	$17\frac{1}{2}$ „
Royal	24	„	$19\frac{1}{4}$ „
Super-Royal	$27\frac{1}{4}$	„	$19\frac{1}{4}$ „
Imperial	30	„	22 „
Elephant	28	„	23 „
Columbier	35	„	$23\frac{1}{2}$ „
Atlas	34	„	26 „
Double Elephant	40	„	27 „
Antiquarian	53	„	31 „
Emperor	68	„	48 „

Of these, Double Elephant and Imperial are the most generally useful sizes. Whatman's cold pressed paper is the quality most usually employed for finished drawings. For ordinary sketching or working drawings, cartridge paper may be used. It bears the use of india-rubber well, receives ink on the original undamped surface freely, shows a good line, but it does not take colours or tints very well. Cartridge paper can be obtained in any length up to 200 yards and in width 53 or 60 inches, and consequently is useful in certain cases. For delicate small scale line-drawing, the thick blue paper imperial size, such as is made for ledgers, etc., answers exceedingly well.

Tracing Paper is a preparation of tissue paper, rendered transparent and qualified to receive ink lines and tinting without spreading. When placed over a drawing already executed, the drawing is distinctly visible through the paper and may be copied or *traced* directly in Indian ink: thus an accurate copy may be made with great expedition. Tracings may be rolled and stowed away very conveniently; but, if likely to be frequently used, they should be mounted on cloth, or on paper and cloth, with paste. Tracing paper becomes brittle with age and will not stand folding and if required as a record a good strong quality should be used in preference to the ordinary thin commercial variety.

Tracing paper may be prepared from double-crown tissue paper by lightly and evenly sponging over one surface with a mixture of one part of raw linseed-oil or nut oil, and five parts of turpentine. Five gills of turpentine, and one of oil, will go over from 1½ to 2 quires of twenty-four sheets.

Tracing cloth is a similar preparation of linen, and has the advantage of toughness and durability.

In colouring drawings on tracing paper or tracing cloth, the colour must be laid on the reverse side of the paper to that on which the lines are drawn.

The colour laid on should be much darker than the tint required in the drawing.

3. Mounting Drawing paper on Drawing boards.—The edges of the paper should be first cut straight, and as near as possible at right angles with each other; also the sheet should be so much larger than the intended drawing and its margin, as to admit of being afterwards cut from the board and yet at the same time one half inch smaller than the board on which it is to be mounted.

The paper must be first thoroughly and equally damped with a sponge and clean water, *on the opposite side from that on which the drawing is to be made.* When the paper absorbs the water, which may be seen by the wetted side becoming dim, as its surface is viewed slantwise against the light, it is to be laid on the drawing board with the wetted side downwards, and placed so that its edges may be nearly parallel with those of the board having first well wetted strips of stiff foolscap or ordinary cartridge paper about 3½ inches wide. These strips should now be slightly dried on a piece of blotting paper and one side pasted with strong paste. Each strip will be applied with an overlap of ½ inch on the drawing paper and the remaining portion passed along the edge of the board and fastened underneath and the process continued all around, necessary lengths being torn off. This is how a planetable is usually mounted and it is a more convenient way than pasting the edge of the actual drawing paper on to the board, for a penknife passed underneath the pasted strips brings the drawing away without the unsightly gashes in the wood work of the board made by a knife cutting through the drawing paper.

The mounted paper should be allowed to dry gradually, and the process should not be hastened by putting it before a fire or in the strong sunshine, otherwise the unpasted portion, which dries more quickly than

the pasted portion, is very apt to tear itself away from the pasted border. A small quantity of alum is a very good thing to mix with the paste, for it not only enhances the adhesive properties of the paste, but the drawing paper, when dry, is not so stiff as if paste only is used.

Mounting Drawing paper on Canvas or Linen.—If however the plane-table section is to remain on the board for some time and receive a certain amount of rough usage and is also to be kept as a permanent record such as the originals of the Survey of India the following procedure is recommended. First secure a piece of muslin or rough calico, wet and stretch it well. Its size should be about $3\frac{1}{2}$ inches larger than the plane-table. Place the cloth on the planetable and smear the surface of the cloth with paste removing all lumps and continue as in previous paragraph by placing the damped drawing paper on to the pasted cloth and finishing by the pasted strips of paper using paste freely along the edges both for the strips and cloth. Only a certain amount of paste passes through the cloth to the table so it is easily rolled off with a ruler.

4. The Pencil, either an H, or an HH, should have a moderately fine point and when being used should be gently pressed upon the paper, and slightly inclined in the direction in which the line is being drawn, care being taken to keep it, throughout the operation, in the same position with reference to the ruler.

The worker in the field will find that a 6 H will be none too hard in the hot weather after a few days' work, certainly a 2 H would be too soft. A pencil point protractor is a cheap and useful article to have. The lead can be best kept sharp on a small smooth file, or better still on a piece of glass paper stuck to the legs of the planetable stand.

5. Indian Ink.—If a stick of ink is used, it should be carefully rubbed up with water, a drop or two to start with, gradually increasing the quantity ; it should be free from grit and above all, not too thick. One or two trials by drawing two or three lines on a piece of waste paper will show if more rubbing is required. Great care should be taken to see that it is worked up sufficiently to ensure a thoroughly black line. Ink should be made fresh daily. Indian ink when stale gives brown lines and is not water proof. Liquid Indian ink, of excellent quality, however, can now be obtained and is in many ways more convenient to use than stick Indian ink.

6. Instruments.—A case of instruments generally contains :—

(*a*) Compasses with movable parts—(1) Plain Point; (2) Pencil Point; (3) Ink Point; (4) Lengthening Bar.
(*b*) Ink Bow Compass.
(*c*) Pencil Bow Compass.
(*d*) A set of Spring Bows—(1) Dividers; (2) Pen*; (3) Pencil.*
(*e*) Drawing Pens.
(*f*) Plain Dividers.
(*g*) Parallel Ruler.
(*h*) Pricker.
(*i*) Protractor.
(*j*) Marquois' Scales.
(*k*) Sector.
(*l*) Proportional Compass.
(*m*) Curves.

Cheap cases do not contain all these instruments, while some draftsmen use many other varieties. Other useful instruments are :—

(1) Set squares. | (2) T-Square.

(3) A Beam Compass.

(*a*) Compasses should be held at the top between the forefinger and thumb, with one or more fingers under the hing to increase or diminish the distance between the points gradually and without a jerk; in all cases the steel point should be guided by the finger of the other hand to the centre of the circle to be drawn, or to the line or scale to be measured. When several concentric circles are to be drawn, great care is requisite to avoid enlarging the centre hole. Persons unaccustomed to the use of compasses are very apt to turn them over and over in the same direction when spacing off a number of equal distances on the divisions of a scale. This necessitates a constant change of the hold by means of the finger and thumb, which often causes the point of compass to be forced into the paper, or to be jerked off the fixed point altogether. To obviate this, the points of the dividors should be worked alternately above and below the line along which the divisions are being set off, by this means the manipulation will be much more delicate, and there will be no liability of the compasses shifting.

(*b*) The Drawing or Line Pen.—In using a pen, dip it into the ink and wipe the outside of the points clean with a rag. The pen is now ready for use. Hold the pen lightly against the ruler, taking care that it is vertical as the points have been ground by the maker so as to give the

* The pump bow ink and pencil for making circles is far superior to the type sold in instrument boxes.

best lines when used *vertically;* be very careful to make both nibs touch the paper, to preserve an even pressure and the same position of the pen with regard to the paper and ruler throughout with a *slow* but equal motion along the ruler. The pen should not be tested by ruling on the hand which is greasy but on a sheet of stiff paper. By attending to these points, the pen will mark throughout the whole length of the line, an equal thickness of line being secured, and rugged edges avoided. If after working some time it is found that the ink does not run freely from the pen, it may be amended by passing a small slip of paper (not blotting) between the nibs. Above all things the paper must be kept clean : it should not be touched by the hands more than possible, as the hand makes the paper greasy ; and when once the paper has acquired this defect, clean sharp lines are impossible. In inking in over pencil lines, work from the top of the paper towards the bottom ; this will prevent any risk of smearing. The pen should be carefully cleaned and dried before being laid aside.

A drawing pen should have its nib ends exactly uniform in length and width and the points should be as thin as it is possible to set them. A hone is all that is needed to set the points of the nibs.

(*c*) Parallel Rulers.—These are of two kinds :—

(1) *The plain parallel ruler.*—This should be tested to see that the distances between the pivots on the rulers and the lengths of the bars are exactly equal in each case.

(2) *The rolling parallel rule* :—This should be heavy enough to ensure stability. It can be tested by running it in one direction and ruling two parallel lines and then reversing the run and noting the error, if any, between the lines drawn at the end of each run. For accurate work it is best to avoid all parallel rulers and to use Marquois' scales.

(*d*) Protractor.—The most general use of the protractor is for setting off upon paper any given angle. A variety of scales are, however, drawn on both sides of the instrument which are extremely convenient.

The following is a detailed description of the method of using the protractor :—

The *protractor* is generally a rectangular piece of ivory or boxwood 6 inches long by $1\frac{3}{4}$ inches to 3 inches broad. Round three of its edges the angles are marked (the lines radiating from a point in the centre of the fourth side) and should be numbered in two rows, the outside from 0° to 180°, and the inside from 180° to 360°. The method of using it to set off any required angle is easily seen by an example.

Suppose we wish to draw from the point C in the line CA another line making an angle of 40° with CA [*Fig.* 1, *Plate* I.] Place at C the centre mark on the lower edge of the protractor, and keeping it there, move the protractor round till the line numbered 40°, on the radiated edge, coincides with CA. Draw the line CD along the edge; DCA is the required angle, which has thus been simply transferred from the scale to the paper. When the line CA is not long enough to admit of the above construction, it will be necessary to place the lower edge of the protractor on that line, with the centre on C [*Fig.* 2. *Plate* I.], then to make a mark against the upper edge at the line indicating the required angle, and removing the protractor, draw a line through the two points.

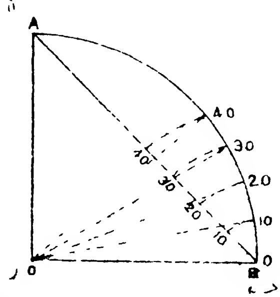
Protractors are usually of two patterns—The draftsman's pattern and the military pattern. The draftsman's pattern contains a variety of scales on both sides—they are simple scales. Those marked 30, 35, 40, 45, 50, 60, being the same as those on the Marquois' scale described further on (page 8). These numbers simply representing the number of parts into which the inch is divided, *i.e.*, on the 30 scale, thirtieths of an inch can be taken off; on the 40 scale, fortieths of an inch, and so on. The use of these scales is found when we have to employ for a drawing a scale such that one of these divisions represents a convenient unit of measurement, such as 1 foot, 1 yard, 10 feet, 10 yards, etc., etc.

The scales marked in $\frac{3}{8}$, $\frac{3}{4}$, etc., etc., are also simple proportional scales. The numbers $\frac{3}{8}$, $\frac{3}{4}$, etc., refer to the length of one division, which is divided into 12 parts. That marked In. being one inch long, that marked, $\frac{3}{4}$, $\frac{3}{4}$th of an inch long, and so on. These scales are useful for measurements involving feet and inches on account of the duodecimal minor divisions. They are not generally so convenient, however as the other scales just described. The diagonal scale is an ordinary one. The inch being divided into 10 parts 1/100th of an inch being obtained by means of the diagonal lines; where the $\frac{1}{2}$ inch is divided into 10 parts, we can, of course obtain 1/200th of an inch. The principle of this and the method of construction will be explained further on.

The scale marked Cho., is a scale of chords, and deserves attention. It is constructed in this manner:—Take a quadrant AOB, *Fig.* 3, divide the arc into arcs of 10°, and number these 10, 20, 30, up to 90, from B to A. Join AB, and with B as centre and radii from B to these various divisions describe arcs cutting AB, in the points 10, 20, 30, etc. These various radii are the chords of the different arcs; consequently AB is called a scale of

chords. Each scale will vary with the length of the radius ; but Euclid, IV 15, proves that the side of a hexagon is equal to the radius of the circumscribing circle ; or in other words, the radius of the circle = the chord of 60°.

Fig. 3.



To use the scale.—With centre C [*Fig.* 4, *Plate* I], and radius equal to the distance from zero to 60° on the scale [*Fig.* 1, *Plate* I], describe an arc HK, cutting CA in H and with centre H, and radius equal to the distance from zero to 40°, or other given angle, describe an arc intersecting HK in K join CK ; KCH is the required angle.

This method of protracting angles is much to be preferred to simply laying them off by the protractor, as it is more accurate, and the greater the radius the greater the accuracy.

The military pattern protractor generally differs from the above in having none of the above scales marked except the diagonal scale. As it is usually used for surveying purposes, in place of the scales described above, scales of one, two, four, six and eight inches to the mile are given, together with a normal scale of horizontal equivalents. The protractor can also be used as a clinometer, by boring a small hole near the edge of the protractor and suspending a small weight by a thread.

(*e*) Marquois' Scales.—The box of *Marquois' Scales* contains two rectangular rulers and a right-angle triangle, of which the hypotenuse or longest side is three times the length of the shortest. Each ruler is a foot long, and has parallel to each of its edges, two scales, one placed close to the edge, and the other immediately within this, the outer being termed the artificial and the inner the natural scale. The divisions upon the outer scales are three times the length of those upon the inner scale, so as to bear the same proportion to each other that the longer side of the triangle bears to the shorter. Each inner, or natural scale, is in fact, a simply divided scale of equal parts having the primary divisions numbered from the left hand throughout the whole extent of the rule. In the artificial scales the zero point is placed in the middle of the edge of the rule and the primary divisions are numbered both ways, from the centre point outwards. Each division on this scale is three times the length of a corresponding division on the natural scale. The triangle has a short line drawn perpendicular to the hypotenuse, near the middle of it, to serve

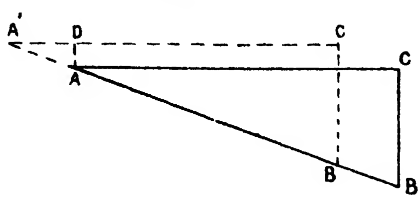
as an index or pointer; and the longer of the two sides has a bevelled edge.

The rectangular rulers have numbers 25, 30, 35, 40, 45, 50, 55, 60 marked on each scale: these numbers simp y show how many divisions the inch is divided into on the natural scale; the artificial divisions being three times the natural division. We are enabled by the method shown below to draw parallel lines from $\frac{1}{25}$th to $\frac{1}{60}$th of an inch part, or any multiples of these fractions. Instrument makers usually number the rulers and triangle and these should be examined to see that they correspond and belong to one set.

To draw a line parallel to a given line at a given distance from it—(1) Having applied the given distance to one of the natural scales, which is found to measure it most conveniently, place the triangle with its sloped edge coincident with the given line, or rather at such a small distance from it, that the pen or pencil passes directly over it when drawn along this edge. (2) Set the ruler closely against the hypotenuse making the zero point of the corresponding artificial scale coincide with the index upon the triangle. (3) Move the triangle along the ruler, to the left or right, according as the required line is to be above or below the given line, until the index coincides with the division or sub-division corresponding to the number of divisions or sub-divisions of the natural scale, which measures the given distance, and the line drawn along the sloped edge in its new position will be the line required.

The proof of this is as follows:—If ABC, *Fig.* 5 represent the triangle in its new position, and the dotted lines represent its original position, by similar triangles ABO, AÁD, AD, : AÁ = BC : BA = 1 : 3 and therefore AD contains as many divisions of the natural as AÁ contains of the artificial scale.

Fig. 5.



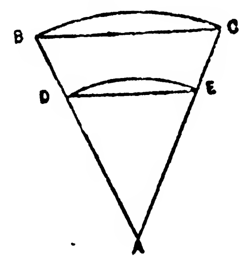
(*f*) Sector.—The sector is a ruler 12 inches long and about half an inch broad jointed in the centre so as to allow of its being folded together, in the direction of its depth. A sector either of wood or ivory is generally supplied with ordinary instrument boxes. A more detailed description of its construction is therefore necessary.

The most important scales and the ones which are really of most service in geometrical construction are the line of lines, the line of chords and the line of polygons.

Line of Lines.—The principle of the use of the line of lines is a follows :—Let the lines AB, AC represent a pair of sectoral lines, and BC, DE any transverse distances taken on this pair of lines ; then, from the construction of the instrument AB = AC and AD = AE, so that

$$AB : AC = AD : AE$$

Fig. 6.



and the triangles ABC, ADE have the angle at A common, and the sides about the equal angle proportional (Euc. VI, 6) ; they are, therefore similar.

$$\text{and } AB : BC = AD : DE.$$

From the above the use of the *line of lines* is self-evident. For example :—

To divide a line 3·11 inches long into 7 equal parts. Take the length of the line into the compasses, and having set one point in the division which is numbered 7, open the instrument till the other point of the compasses meets the 7th division on the other limb, then the distance between the two points marked 1, will obviously be the $\frac{1}{7}$th part of the line as required, or equal to ·44 of an inch nearly ; but it must be observed, that owing to the inevitable imperfection and wear of all instruments, this distance must be stepped along the line to ascertain whether it may not require a small correction.

Example 1.—To determine $\frac{2}{7}$ths of a line 3 inches long ; take that length in the compasses and open the sector until it coincides with the primary divisions 7, 7, when the distance between 2 and 2, is that required.

Example 2.—To find $\frac{9}{23}$rds of a line 4·09 inches long [*Fig.* 7, *Plate* I.]

Since there are only ten primary divisions, recourse must be had to the secondary divisions, to solve this problem. In order to bring the construction some distance from the centre, which will insure the accuracy of the result, multiply the numerator and denominator of the fraction by some number which will make the denominator when so multiplied near, but not greater than 100 : in this case 4 is a convenient multiplier ; then $\frac{9}{23} = \frac{36}{92}$ having taken off 4 09 inches in the compasses, make that length a transverse distance at the secondary division 92, then the transverse distance at 36 will give the part required.

Note.—A *lateral distance* is a distance measured from the centre along any sectoral line. A *transverse distance* is a distance measured from a point in one line of a pair of sectoral lines to the corresponding point in the other line.

(g) Line of Chords—This scale is similar to the one marked Cho. on the protractor, and is used for the same purpose; but the double scales of chords on the sector are generally more useful than the single scale on the protractor; for on the sector, the radius with which the arc is to be described may be of any length between the transverse distance of 60 and 60 when the legs are closed, and that of the transverse of 60 and 60 when the legs are opened as far as the instrument will admit of; but with the scale on the protractor, the arc described must always be of the same radius.

To lay down an angle which shall contain a given number of degrees:—1. When the angle is less than 60°; say 46°.

Make the transverse distance of 60 and 60 equal to the length of the radius of the circle, and with that opening describe the arc BC [*Fig.* 8, *Plate* I]. Take the transverse distance of the given degrees 46°, and lay this distance on the arc from the point B to C. Join AC, AB; the angle CAB is the one required.

2. When the angle contains more than 60°; say 148°.

Describe the arc BCD, making the radius equal to the transverse distance of 60 and 60, as before. Take the transverse distance of $\frac{1}{2}$ or $\frac{1}{3}$, etc., of the given number of degrees, and lay this distance on the arc twice or thrice, as from B to *a*, *a* to *b* and *b* to D. Join BA, AD; BAD is the angle required.

3. When the required angle contains less than 5°, suppose $3\frac{1}{2}$°, it will be better to proceed thus:—With the given radius, and from the centre A, describe the arc DG; and from same point D lay off the chord of 60°, thus giving the point G such that the angle DAG = 60°. From the same point D lay off in the same direction the chord of $56\frac{1}{2}$° (= 60° − $3\frac{1}{2}$°), thus giving the point E such that the angle DEA = $56\frac{1}{2}$°. Then the angle GAE is the angle required.

(h) Line of Polygons.—*The line of polygons* is chiefly useful for the ready division of the circumference of a circle into any number of equal parts from 4 to 12; it forms, therefore, a ready means of inscribing regular polygons in a circle. To do this, set off the radius of the given

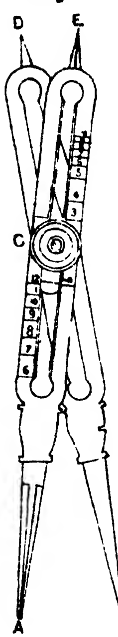
circle (which is always equal to the side of the inscribed hexagon) as the transverse distance of 6 and 6 upon the line of polygons. Then the transverse distance of 4 and 4 will be the side of the inscribed square; that of 5 and 5 the inscribed pentagon, that of 7 and 7 the inscribed heptagon and so on.

It is required to form a polygon upon a given right line, set off the extent of the given line as a transverse distance between the points upon the line of polygons, answering to the number of sides of which the polygon is to consist; as for a pentagon between 5 and 5, or an octagon between 8 and 8, then the transverse distance of 6 and 6 will be the radius of the circle which is to be described so as to contain the given line; if now we set off the length of this line round the circumference of the circle we shall obtain a regular polygon of the required number of sides.

(i) Proportional Compasses—These, though of great service in many problems which occur in plan drawing, are not supplied with the ordinary instrument boxes. A description of the method of using them is, however, considered necessary.

They consist of two equal and similarly-formed parts or limbs AE and BD *(see Fig. 9)*, opening upon a centre C and forming a double pair of compasses whose points are A, B, E, D. When shut up, the two limbs appear as one, and a small stud fixed in one fits into a notch made in the other, and retains the instrument in its closed position. The adjustment of the instrument must be made when both limbs coincide; as it is only in this position that the centre piece C can be moved up and down. The chief use of the proportional compasses is to reduce a drawing in any given proportion. To do this the centre C is shifted up or down as required thereby shortening one set of legs and lengthening the other. The distance to be reduced is measured off with one set of legs, and the distance shown by the other pair will be the corresponding length, reduced or increased from the original length in a ratio depending upon the position of the centre C. As in the sector, various other geometrical constructions can be performed by means of the different scales given on either side of the limbs; it will be sufficient, however, to describe the method of adjusting the instrument for laying off distances on a plan, the scale of which is to bear a certain proportion to that of a given plan.

Fig. 9.



On the face of each limb there are four sets of divisions, one denominated "Lines," a second "Circles," a third "Planes," and the fourth "Solids." It is with the first of these, *viz.*, the Line of Lines, that we have to do.

When the zero of the centre on the dove-tailed sliding piece is set to the division marked 1 on the line of lines, and clamped by turning the mill-headed screw C, any opening of the compasses will give equal distances at both extremities. When the zero is in a similar manner set to 2 on the line of lines, the proportions between the openings of the points A, B, the corresponding openings of the points D, E, will be as 2 to 1, in other words, any distance set off by D, E, will be half the distance measured by A, B. Similarly if the zero be set to 3, the distance set off will be to the distances measured as 1 to 3, and so on for the other divisions which extend up to 10.

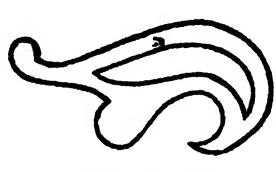
(*j*) Curves.—For curves which are not circular, but variously elliptic or otherwise, "French" curves made of thin wood, of variable curvature, are very serviceable. The two examples (*Figs.* 10 and 11) have been found from experience to meet almost all the requirements of ordinary drawing practice. Whatever be the nature of the curve, some portion of one of these "French" curves will be found to coincide with its commencement, and other portions can be used to complete the curve.

Fig. 10.

"French" Curve—One-fourth full size.

(*k*) Set-Squares.—A few set-squares of various sizes are useful. They consist of triangular pieces of wood, celluloid or vulcanite. One angle is invariably a right angle, and the other angles may be 45, 30 and 60 degrees. Set-squares are used in conjunction with a straight edge for drawing lines at right angles to each other, or for drawing parallel lines.

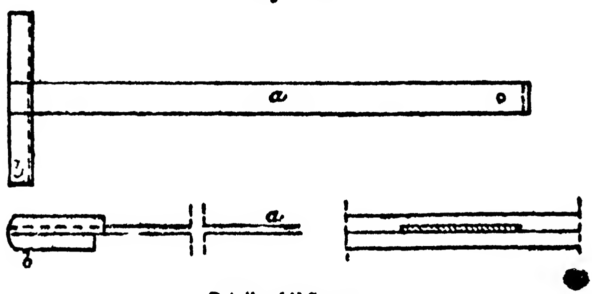
Fig. 11.



"French" Curve—One-fourth full size.

(*l*) T-Square.—The T-Square (*Fig.* 12) is a blade or "straight edge" *a*, usually of mahogany, fitted at one end with a stock *b*, applied transversely at right angles. The stock being so formed as to fit and slide against one edge of the board, the blade reaches over the surface, and presents an edge of its own at right angles to that of the board, by which parallel straight lines may be drawn upon the paper. To suit a 41 inch board, the blade should measure 40 inches long clear of the stock, or one

Fig. 12.



Details of T-Square

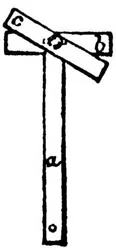
inch shorter than the board, to remove risk of injury by overhanging at the end; it should be 2½ inches broad by $\frac{3}{32}$ of an inch thick, as this section makes it sufficiently stiff laterally and vertically. If thinner, the blade is too slight and too easily damaged by falls and other accidents, and is liable to warp: if thicker, it is too heavy and cumbersome; if broader, it is heavier without being stiffer. The tip of the blade may be secured from splitting by binding it with a thin strip inserted in a saw-cut as shown. The stock should be 14 inches long, to give sufficient bearing on the edge of the board, 2 inches broad, and ⅝ inch thick, in two equal thicknesses glued together. With a blade and stock of these sizes, a well-proportioned T-square may be made, and the stock will be heavy enough to act as a balance to the blade, and to relieve the operation of handling the square. The blade should be sunk flush into the upper half of the stock on the inside and very exactly fitted. It should be inserted full breadth, as shown in the figure; notching and dove-tailing is a mistake, as it weakens the blade and adds nothing to the security. The lower half of the stock should be only 1¾ inches broad, to leave a ¼ inch check or lap, by which the upper half rests firmly on the board, and secures the blade lying flatly on the paper.

One-half of the stock *c* (*Fig.* 13) is in some cases made loose, to turn upon a brass pin to any angle with the blade *a* and to be clenched by a screwed nut and washer. The turning stock is useful for drawing parallel

lines obliquely to the edges of the board. In most cases, however, the sector, and the other appendages above described, answer the purpose, and do so more conveniently. A square of this sort should be rather as an addition to the fixed square, and used only when the level edge is required, as it is not so handy as the other.

The edges of the blade should be very slightly rounded, as the pen will thereby work the more freely. It is a mistake to chamfer the edges—that is, to plane them down to a very thin edge, as is sometimes done, with the object of insuring the correct position of the lines; for the edge is easily damaged, and the pen is liable to catch or ride upon the edge, and to leave ink upon it.

Fig. 13.



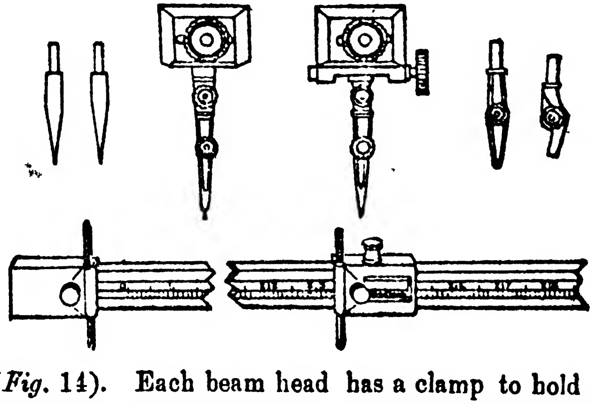
A small hole should be made in the blade near the end by which the square may be hung up out of the way when not in use.

No varnish of any description should be applied to the T-square, or indeed to any of the wood instruments employed in drawing. The best and brightest varnish will soil the paper. The natural surface of the wood, cleaned and polished occasionally with a dry cloth, is the best and cleanest for working with. The wood should be non-oily and well seasoned.

(*m*) Beam Compasses.—Beam compasses are used for setting off accurately distances which are beyond the stretch of an ordinary compass.

They consist of two beam heads moving on a graduated bar of wood or

Fig. 14.



electrum. (*Fig.* 14). Each beam head has a clamp to hold a pointer or pencil. One of these heads is fixed at one end of the bar, and is provided with a vernier screw for making fine adjustments, while the other is free to move up and down on the bar and can be clamped in any position.

If a scale is given on the bar, it should never be used for accurate work, but distances should be taken direct from a scale drawn on the paper on which the plan has been plotted. Beam compasses are used to test the rectangular margins of a sheet, and the perpendicularity of the central meridian line of a survey to a parallel of latitude, by the usual method of checking a right angle, *viz.*, measuring 3 and 4 (or their multiples) on the perpendiculars and testing the hypotenuse with the distance 5 or its multiple.

7. **Printing.**—It cannot be too strongly insisted upon that a finished drawing cannot be produced without first class printing. Too much care cannot be given to this matter, as a good style of printing is essential to the production of a really good engineering or topographical drawing, more especially the latter, as the names of towns and villages are all over the place.

This perfection cannot be attained without a great deal of practice, care and perseverance. It must, however, be pointed out that this perfection should only be expected from, and sought after, by draftsmen and the subordinate ranks.

Engineers and superior officers should seldom waste their time in endeavouring to print up a drawing with fine headings and copper-plate printing. They should content themselves with producing neat and legible words and leave the finished work to their less highly educated inferiors.

The following paragraphs, however, will be devoted to showing how any intelligent man, with care and perseverance, can become a first-rate printer.

(*a*) As a rule Block Printing is decidedly the best for all kinds of headings, being neat and legible. For main headings fancy letters may occasionally be used, but it may be laid down as an axiom that the plainer the lettering on a drawing the better.

Block printing may be either upright or sloping. The proportion of breadth to height varies considerably in different alphabets, and may range from the "square" form in which the breadth is equal to the height, down to the "elongated," in which the breadth is reduced to anything down to one-third of the height.

The first thing to do is to decide the height of the letters it is proposed to use for a heading. This must entirely depend on the size of the drawing and should be strictly in proportion. Having decided the height, it is next necessary to decide the proportion of breadth to height.

The most symmetrical in appearance and the easiest to execute is an alphabet in which the breadth of the larger number of the letters is four-fifths of the height. Divide the height selected into five spaces (*Plate* II).

Then most of the letters are four of these spaces broad. The exceptions are—I = 1, J = 3, F, L, = 3½, M, T, W, = 5. The spaces between the letters may be 2 or 1½, and between the words 5 or 6 according to taste.

Then to put in a heading, after selecting size, write it roughly thus—

P	L	A	N	A	N	D	S	E	C	T	I	O	N		
4	3½	4	4	4	4	4	4	4	4	5	1	4	4	spaces =	53½
2	2	2	6	2	2	6	2	2	2	2	2	2		„ =	34
														Total =	87½

Take 87½ spaces and place centrally. Then rule the boundary lines *of each letter* and *after, if necessary,* the single space lines within each letter. This gives as little ruling as possible and also gives spaces correct. If single space lines are ruled all along, one letter of the 3½ breadth throws out all those after it.

If a more upright narrower style is required, instead of taking spaces $\frac{1}{5}$th the height, take them $\frac{1}{6}$th or $\frac{1}{7}$th.

It should be borne in mind that the terminations of all letters should be always flat, never pointed or rounded.

One of the difficulties of the beginner is to know what is bad and what is good printing, it will, therefore, be useful to point out a few of the mistakes to avoid, and points to be noted in the formation of certain letters. Refer for each letter to Plate II.

In the letter A, the cross stroke should be about one-third of the way from the bottom of the letter.

In the letter B, the upper portion should be about one-tenth smaller and not quite so broad as the lower portion.

In the letter C, take care that you place the lower termination exactly below the upper one.

In the letter E, the upper horizontal stroke should be slightly shorter than the lower one, but be careful to avoid exaggeration.

In the letter G, avoid all fancy forms.

In the letter K, the upper diagonal meets the perpendicular stroke two-thirds of the way down. The lower diagonal joins the upper one in such a position that if it were produced it would meet the perpendicular stroke one-third of the distance from the top.

The letter M requires to be treated with a certain amount of discretion; if the strokes used are broad the letter should be five spaces broad to avoid looking heavy; if the strokes used are thin the letter should be only four spaces broad.

In the letter R the lower termination of the tail should be flattened.

The letter S is a very difficult letter to form ; the upper half should be less broad than the lower, and a horizontal line dividing the upper and lower curves should be nearer the top than the bottom. If the two curves are made the same, the letter will look top-heavy as may be seen in the Plate.

The upper stroke of the letter Z should be somewhat shorter than the lower stroke.

(*b*) Italic Printing (Plate III), is well adapted for the information to be entered on ordinary plates and surveys. To execute this, the beginner should rule three lines parallel to each other to regulate the heights of the small letters and capitals. The distance apart of these lines will depend on the size of the printing desired, but lines three and four-sixtieths apart will be found convenient to start on. Parallel lines should then be ruled at intervals of about half an inch to define the slope of the printing.

The beginner should pencil each letter in with the greatest care before inking in, avoiding the use of india-rubber. When he has gained sufficient proficiency through practice, the pencil may be dispensed with. Students should remember that it is impossible to print after taking any violent exercise as the hand is not sufficiently steady.

In Plate IV, is given an example of another style of printing, which is fairly easy to acquire and which may be occasionally useful.

Plate IV A, is now the accepted rapid style in which drawings may be finished. Field notes and figuring in this style is recommended as it lends itself to any class of nibs and especially medium pointed fountain pens. The style is easily learnt and variations of it will be recognized in most recent plan drawings and survey maps.*

8. General Rules applicable to all Geometrical Drawing.—(1). Instruments, *especially ruling pens*, should be kept scrupulously clean. *Clean drawings* cannot be executed without *clean hands*. Keep a piece of paper under the hand when working. Wooden and ebonite rulers can be cleaned by rubbing them with bread. Always rub them on a piece of paper before commencing work.

(2). Never draw a single line that is not absolutely necessary. Always work with a sharp point to your pencil. Do not cut it at the lettered end.

* Messrs. Reeves and Sons, London, are the makers of Manuscript Nibs specially suited for printing.

Pencil work should be done as *lightly* as possible. If the lines are heavy they are difficult to rub out and soil the rulers.

(3). If lines are drawn wrong, mark them lightly with one or two dashes; but as a rule omit all corrections of pencil work with rubber till the plan is inked in and then at one operation rub out all the pencil lines. Every use of the rubber raises the paper surface into a roughness in which dust catches and gets ingrained.

(4). No attempt should be made to produce a finished pencil drawing, the outline only should be drawn in pencil and no shading or shadow lines as the lead rubs off and dirties the paper.

(5). When about to draw a right line between two points, place the ruler as nearly as possible in the same position with reference to both and then *see* whether the line will pass exactly through both points, before drawing it on the paper with either pen or pencil. Also in drawing an arc through several points, try it with plain dividers, to see if the centre is exact before drawing the line.

(6). All lines should be drawn sufficiently long at first, to avoid the necessity for subsequently producing them; a long line should never be obtained by producing a short one, unless some distant point in the prolongation has been first found by other means.

(7). Whenever it is practicable lines should be drawn *from* a given point and *not* to it; and if there are several points, in one of which two or more lines meet, the lines should be drawn from that one to the others; thus, radii of a circle should be drawn from the centre to points in the circumference.

(8). The larger the scale on which any problem, or part of one, is constructed, the less liable is the result to error. Hence all angles should be set off, and points determined by means of the largest circles which circumstances will allow to be described.

(9). In determining a point by the intersection of circular arcs or straight lines, the radii should meet at that point at an angle of not more than 30°.

(10). When one arc or straight line intersects another, as above, the second arc or line need not be drawn, but the *point* of intersection *only* should be marked, so as to avoid unnecessary lines.

(11). Avoid setting off equal lengths on a given straight line by continual repetition of one such length, but mark off on the line a convenient multiple of the given length, and sub-divide it, *i.e.*, work from

the whole to part, not from part to the whole; this is a great principle in surveying as well as plan drawing, and is especially to be observed in the construction of scales.

(12). In laying off a length along a line with a scale, it is always well to check, either by reading off the distance along another part of the same scale, or by applying the scale so that it shall read backwards. This is a simple check and a very useful one, as in plotting a survey it may often prevent considerable unnecessary labour.

(13). Every drawing should have one or more long lines put in first across the paper and at right angles to these; all new lines should be laid off from these guide lines, not from short lines of some part of the plan. The right angle guide lines should be laid with the compasses in the ordinary geometric way, not with the protractor. If a T-square and large set square is used, this should be more accurate than any other way if carefully managed.

9. Instructions for the preparation of finished Topographical Drawings.—Drawing Paper.—The drawing paper should be carefully examined to see which is the right side and that no mouldy spots exist. If any such spots are detected, the paper should be rejected, as it is impossible to paint over the discoloured spots. The paper is right side towards the draftsman when held up to the light and the name of the maker reads correctly.

Scales.—Before commencing any large drawing, the scale on which it is to be made should be carefully constructed at the foot of the paper. All measurements should be taken from this scale. No discrepancy will then exist, when the paper is removed from the board, between the measurements on the drawing and the corresponding ones on the scale. Such discrepancy is often very considerable when separate pieces of paper are employed for the scale and drawing; paper is very sensitive to atmospheric conditions, and often shrinks considerably after removal from the board. For purposes of computing areas the paper should be ruled up (in cobalt) into one inch squares.

The drawing.—The drawing should now be put in with fine pencil lines, which, when complete, may be inked in with a fine drawing pen and the best Indian ink. No thick ink lines are on any account to be drawn till all the colours have been laid on. Care should be taken not to

overshoot the corners where two lines intersect and the lines should be kept as fine as possible.

Circles and arcs of circles should be inked in before straight lines. In drawing circles, care must be taken not to allow the point of the compass to penetrate the paper, the holes thus formed are liable to become filled up with colour and cause an unsightly blemish. The fine outlines of the drawing having been inked in, the paper should be thoroughly cleaned with dry clean bread and india-rubber, but the latter should be used as sparingly as possible.

Flat washes.—In laying on a flat wash the drawing board is always to be inclined so as to let the colour float downwards, the brush being only needed to give direction. If the paper is horizontal, the wash, remaining stagnant on one spot, deposits some of the solid colouring matter on the paper as a kind of precipitate, thus giving rise to unsightly blotches and cut shades. It is quite unnecessary to wet the paper before laying on a flat wash if the following directions are observed :—

Sufficient colour should be mixed to last for the whole of the wash required, any sediment should then be allowed to settle, and the clear solution poured off into another saucer. A wash should never be commenced without having a piece of blotting paper handy. A large brush should be used and the colour kept running across the paper, working it gradually down the slope, and no portion of the "working" edge of the colour should be allowed to dry up even for a second till the whole wash is completed. The brush if used full of colour and the colour carried down, stroke by stroke, will ensure a fine even wash. The brush should be replenished with colour as soon as half its contents are used up except towards the end of the drawing when only that quantity sufficient to cover the remaining surface is retained in the brush. Red lines should not be washed over, or the colour will run. When a flat wash is uneven, or contains a cut shade (probably from allowing that portion to dry), or it is required to take outlines, or washes of colour, which are mistakes in the drawing, use a small soft sponge dipped in water, but not too full, apply the sponge boldly but lightly, and have a piece of blotting paper at hand with which to blot off the moisture. Where the colour to be erased is near other colours which the sponge might also touch, an aperture should be cut in a piece of paper of the exact dimensions of the extent to be washed, the paper is then held firmly down upon

the drawing, so that only the required portion of it is visible, and the sponge can then be applied without risk of soiling the adjacent parts of the drawing. The sponge should never be used, either for, or near to, thick ink lines; the ink is sure to run. Ink lines on tracing cloth can be taken out by means of a moist brush and some blotting paper. The spot operated upon, will, however lose its glaze, and any ink line drawn over it afterwards will be liable to run. When as is often the case, a blot or small blemish in a flat wash of colour has to be erased and fresh colour to be afterwards applied, it is important to keep the texture of the paper as intact as possible, the india-rubber should, therefore, be passed very lightly over the previously slightly moistened spot, and this operation should be repeated till a perfectly clean surface is obtained. The colour is then to be stippled in by separate strokes, not washed in; as in this latter case, the rough surface of the paper produced by rubbing would take the colour unevenly, and cause an unsightly blotch.

Choice of tints.—The main point to bear in mind is to preserve harmony in the drawing. Bright colours go with strong lines and bold printing; while light shades, fine lines and unobtrusive printing go together.

10. Conventional Signs.—It is obvious that some convention or method is desirable to obtain a uniform representation of each material or object by a colour or sign. The conventional colours and signs given below include those adopted by departments in India (subject to corrections). Only the most important conventions are given, but there are many others which are used in special branches, such as Irrigation and Military Surveys, the details of which can be obtained from the various conventional charts. If any special signs or abbreviations are used, a table showing their meaning should be attached to the plan drawing.

LIST OF GENERAL COLOUR CONVENTIONS IN USE.

Hills	...	Brown (Burnt Umber).
Sand hills	...	Ditto.
Natural drainage ...	...	Black.
Tanks or jhils	...	Cobalt blue, if perennial, otherwise black.
Natural ravines and dry nalas	...	Black.
Rivers and streams ...	...	Cobalt blue, if perennial, otherwise black.
Village sites { Brick houses	...	Vermilion.
Village sites { Mud houses	...	Brown also vermilion.
Roads, metalled ...	...	Vermilion.
Roads, unmetalled ...	...	Vermilion (Broken lines).
Railways	...	Black.
Canals	..	Blue.

11. Construction of Scales.—When anything which has to be represented on paper is so large that it would be inconvenient to make a full-sized drawing of it, the drawing, or map, is made to another scale, that is, each line in the plan, using this word as a general term is made, with a fixed and known proportion to the line it represents.

Suppose, for example, that in a drawing of a house a line one inch long represents in plan a wall 100 feet long. Then, if the drawing is "drawn to scale," every other detail of the house will be represented by lines drawn in the same proportion. This proportion is called the scale of the drawing, and in this case the drawing is said to be drawn to a scale of 100 feet to an inch. Further, it is evident that the actual length of each piece of the building is 1,200 times the length of the line which represents it in the drawing; or every line in the drawing is $\frac{1}{1200}$th part of the corresponding line in the object. This fraction which represents the proportion of the drawing to the object, is called the "*Representative Fraction*," and this fraction should be entered in a conspicuous place on every plan. The student must clearly understand what is meant by the representative fraction, to find which he must reduce the number of units represented by 1 inch in plan to inches. This will be the denominator of the fraction. The numerator will invariably be 1.

For example—Find the representative fraction of scale of one furlong to an inch.

The denominator is then $12 \times 3 \times 220 = 7,920$, and the representative fraction is $\frac{1}{7920}$.

In addition to the representative fraction, some means must be given by which any distance on the plan may be measured off, and the real length of the object represented may be ascertained.

Scales may be divided into—(1) Plain Scales. (2) Comparative Scales. (3) Diagonal Scales. (4) Vernier Scales.

Before proceeding to consider the construction of scales it will be necessary to show how a given line can be divided into any desired number of parts, as this construction is frequently required in the construction of scales.

To divide a given line AB into five equal parts (Plate VI., Fig. 1).

From the point A in the given line AB, draw a line AC making any convenient angle with the line AB. This angle should not be too acute.

Along AC mark off five equal divisions 1, 2, 3, 4, 5. Join 5B. Through 1, 2, 3, 4, draw lines parallel to 5B, cutting AB in P_1, P_2, P_3, P_4. These points will divide the line AB into five equal parts. Care should be taken to arrange the length of the divisions taken along AC in such a manner that the line 5B may be nearly at right angles to AB. If the angle at which the line 5B meets AB is too acute, it will be difficult to fix the points of intersection P_1, P_2, P_3, P_4, exactly.

12. Plain Scales.—In all scales it is evident that if they fulfil the functions explained above, the unit of length of the scale must bear the proportion shown by the representative fraction to a real unit, and any length on the scale the same to the real length.

We will now give a few example embodying the chief points to be kept in mind in the construction of scales.

Example 1. To construct a scale of 100 feet to an inch to read to 10 feet (Plate VI, Fig 2).

Scales are usually made about 6 inches long. For this case 6 inches will be found convenient as it represents 600 feet.

Draw a line 6 inches long and divide it into six equal parts.

The left hand division is always used to show the smallest unit required, in this case 10 feet. Divide this division into 10 equal parts. These will each represent 10 feet. Ink in two lines for the scale $\frac{4}{60}$th of an inch apart, the bottom one being darker than the top one. Draw perpendicular lines $\frac{8}{60}$ths of an inch high to show the primary divisions, and $\frac{4}{60}$th of an inch high to show the secondary sub-divisions. The right hand point of the left hand division is invariably marked 0 ; the secondary sub-divisions starting from that point are marked from right to left, and the primary divisions from left to right. Print in the title of the scale and the representative fraction, and the unit (feet) which the primary and secondary divisions represent. On the right hand side of *Fig.* 2 are shown convenient distances at which the various lines for construction and printing may be drawn.

Example 2. The representative fraction of a plan is $\frac{1}{60}$, construct a scale to read to feet. (Plate VI, Fig. 3).

Here 60 inches, or 5 feet, represent one inch, and 6 inches on the scale will represent 30 feet. Lay down 6 inches and divide it into

three parts and the left hand sub-division into 10 parts. Finish as in example 1.

Example 3. To construct a scale of 13 yards to an inch to read to yards (Plate VI, Fig. 4).

Here do not follow the too common error of laying down inches and dividing the left hand inch into 13, and numbering the others 13, 26, 39, etc., so that nothing can be conveniently measured on it, but proceed thus. Here 13 yards equal 1 inch, therefore 6 inches represent 78 yards. The nearest next numbered scale to this will be 70 yards, *i.e.*, 10 units to left, and 60 to right, of zero. So, as 78 : 70::6 : 5·39. Lay down 5·39 inches and divide into 7 parts, and the left hand part into 10. Representative fraction, $\frac{1}{13 \times 3 \times 12} = \frac{1}{468}$.

For the method of laying off a distance of 5·39 inches, *see* Diagonal Scales, Example 13.

Example 4.—To construct a scale of 2 miles to the inch, showing miles and furlongs. (Plate VI, Fig. 5).

Here 6 inches = 12 miles but 1 mile to left and 11 miles to right would not look well. So, as 12 : 11 :: 6 : 5·5 inches. Lay down 5·5 inches, and divide into 11 spaces, and divide the right hand space into 10. Representative fraction, $\frac{1}{12 \times 5280 \times 12} = \frac{1}{126720}$.

Example 5.—To draw a scale of 6 inches to a mile to read to yards. (No figures are given for Examples 5, 6, 7 and 8).

It will be most convenient to draw primary divisions to show 1,500 yards and secondary sub-divisions to show 100 yards. Six inches represent 1760. So 17·6 : 16 :: 6·0 : 5·45.

Lay down 5·45 inches and divide as usual. Representative fraction, $\frac{6}{1760 \times 12 \times 3} = \frac{1}{10560}$.

Example 6.—To construct a scale of 8 inches to the mile, in paces of 30 inches.

Here 8 inches = 5,280 feet, or $\frac{5280}{2 \cdot 5}$ = 2,112 paces. Then say 1,600 paces is the length chosen. As 2112 : 1600 :: 8 : x, etc.

Example 7.—To construct a scale of $\frac{1}{20000}$ showing chains of 100 feet.

Here 1 foot = 20,000 feet, and 6 inches = 10,000 feet, or 100 chains. Then 110 chains will be the length of the scale. So, as 100 : 110::6 : etc.

Example 8 —The representative fractions of two plans of a Russian fort are $\frac{1}{800}$ and $\frac{1}{1260}$. Construct a scale of French toises for the former, and one of Russian archines for the other. The toise = 2 13142 yards, the archine = ·7777 yards.

In the first, 1 toise or 2 13 yards = 800 toises Reduced to inches, 76·73 inches on plan equals 800 toises, or 7·67 inches = 80 toises. Thus 60 will be nearest suitable length for scale, and 80 : 60 :: 7 67 : etc., etc. The other is just similar.

Example 9 —In a rapid reconnaissance, when time will not admit of distances being measured by a chain or perambulator, they can be roughly measured by time. If the rate of a horse is known, when trotting or at a gallop, etc , a scale can be made by which distances are at once taken off from simple observations on the time which has elapsed. (Plate VI., Fig 6.)

Suppose a scale of 6 inches to a mile $(\frac{1}{10560})$ is required, adapted to the paces of a horse which trots at the rate of 240 yards a minute.

Then in 9 minutes a horse will trot 2,160 yards. Make a scale of 6 inches to a mile to show 2,160 yards. The length of this line will be 10560 : 2160 × 36 :: 1 : 7·36.

Lay off a line 7·36 inches long and divide it into 9 equal parts. Each part will represent the distance over which the horse travels in a minute, or 240 yards. Sub-divide the left hand division into 6, which will then read to 10 seconds.

13. Comparative Scales.—When the given scale of a plan reads in a certain measure, *and it be desired to construct a scale* for the plan reading in some other measure, this new scale is called a comparative scale.

Thus if the scale of the plan of a French building reads in decimetres and it is desired to take measurements off the plan in feet, a comparative scale must be constructed. The main point to bear in mind is that the representative fractions of the two scales must be the same.

Example 10.—The scale of an Indian plan is drawn in Haths. It is found by measuring the scale that one inch represents 6 75 Haths. It is required to draw a comparative scale of feet.

(Hath = 18 inches.) (Plate VI., Fig. 7.)

The representative fraction is $\frac{1}{6.75 \times 18} = \frac{1}{121.5}$.

Take a length of scale to show 60 feet, then

$$121{\cdot}5 : 720 :: 1 : 5{\cdot}92.$$

Lay down a line 5 92 inches long and divide it into 6 parts, and the left hand division into 10 parts. These now represent feet.

Example 11.—The scale of a map of France is in French leagues (1 French league = 4262·84 English yards). It is found by measuring the scale that 3·75 inches represent 25 leagues. Construct the corresponding scale of English miles. (Plate VI., Fig. 8.)

Here 25 leagues $= \frac{4262.84}{1760} \times 25 = 60.5$ miles.

Consequently, 60·5 miles are represented by 3·75 inches, so the scale may show 110 without being very long So, 60 5 : 110 :: 3·75 : 6·81.

Divide then a line 6 81 inches long into 11 equal parts, to show tenths of miles; sub-divide the first primary division into 10 equal parts, to show miles.

Example 12.—A map is drawn to a scale of 2 miles to an inch ($\frac{1}{126720}$). Construct a comparative scale of Russian versts (No figure is given.)

1 Russian verst = 1166 6 English yards.

As the two scales must have the same representative fraction, this question is at once reduced to that of making a scale of $\frac{1}{126720}$ to show versts. But it can also be found directly as follows :—

As one inch represents 2 English miles, and 2 English miles $= \frac{1760 \times 2}{1166.6}$ Russian versts, therefore one inch will represent $\frac{1760 \times 2}{1166.6} = 3{\cdot}02$ versts. The scale will be best 21 versts long.

$$\frac{1760}{1166.6} \text{ versts} : 21 \text{ versts} : : 1 \text{ inch} : x \text{ inches.}$$

$$\therefore x = \frac{21 \times 1 \times 1166.6}{1760 \times 2} = 6{\cdot}96 \text{ inches.}$$

Set off a line 6·96 inches long, and divide it into 21 parts, each part will represent a verst. Divide left hand space into quarters.

In *Plate* VII., *Fig* 1, is shown another sort of comparative scale which is sometimes useful in enlarging or reducing a plan.

If the same distance on two plans on different scales be represented by AB and AC, then all lines parallel to BC will cut off lengths from A in the proportion of AB : AC. Therefore, taking any measurement on one

plan in the compasses, and applying it from A along its line, say AB, the length of the same measurement on the other plan will be found by moving the right leg of the compasses down the cross line AC to C.

14. Diagonal Scales.—It will be seen from the preceding examples that some method of representing a decimal notation is often required. Further, on a plain scale it is only possible to read in two dimensions, such as yards and feet, inches and tenths of an inch, etc. It may be desired to read in three dimensions, such as yards, feet and inches, tenths of inches and hundredths of inches. For this purpose a diagonal scale is used.

Example 13. To draw a diagonal scale of inches, to read to one hundredth of an inch. (Plate VII., Fig. 2.)

Draw a line 6 inches long and divide it into 6 parts. Divide the left hand sub-division into 10 parts, and at the extreme left raise a perpendicular. On this perpendicular lay off 10 equidistant points, and through them draw 10 lines parallel to the scale line. Divide the top line in the left hand sub-division into 10 parts. Draw lines straight up through the divisions right of zero, but to the left of zero, draw diagonal lines to one division to the left on the top line, and number as shown in the figure.

Then it is evident that each division we move along the bottom line from 0 to 10 we get $\frac{1}{10}$, $\frac{2}{10}$, etc., further from zero, but if we move along one of the diagonal lines, say from zero to the first division to the left on the top line, then every time a fresh line is crossed, we have moved $\frac{1}{100}$th of an inch further from zero.

The cross marks on the figure show 3·69 and 5·32 inches respectively reading from the top.

The main point to remember in drawing a diagonal scale is, that the left hand sub-division must be divided into the number of units of the second dimension required, and the number of parallel lines drawn above the scale line must be the same as the number of units there are of the third dimension in a unit of the second dimension.

For example, if it was required to draw a diagonal scale of yards, feet and inches, the primary divisions would be yards, the left hand division would be divided into 3 for feet, and the number of parallel lines required would be 12.

Latitude and Longitude.—Diagonal scales are invariably used for plotting data on geographical maps and since geographical maps are

divided up into graticules of some integral part of degrees, a scale of degrees, minutes and seconds will be required. Take for example a standard map of India on the scale of 1 inch to a mile which is 15′ in longitude and 15′ in latitude; the scales suitable for plotting would be of 5′ each. To make the scales, take off one-third of the length in latitude and in longitude, divide each into fifths and number from the left hand side 1, 0, 1, 2, 3, 4. The space 1 to 0 divide into sixths and with 10 divisions laterally each diagonal part will be $\frac{1}{10 \times 6}$ or $\frac{1}{60}$ of a minute = 1 second. It must be noted that except at the equator the scales for longitude and latitude will be of different lengths.

15. Vernier Scales.—Vernier scales are sometimes used instead of diagonal scales. The principle on which they are constructed is as follows:—If we have any length of scale representing n units of measurements and divide it into n equal parts, each will represent one unit. If now we take a line equal to $(n + 1)$ of these units, and divide it also into n parts, each minor division will be equal to $\frac{n+1}{n}$ units, and the difference between one minor division of the last and one minor division of the first will be $\frac{n+1}{n} - \frac{n}{n} = \frac{1}{n}$ of the original unit. And similarly, the difference between two divisions of the one and two of the other will be $\frac{2}{n}$ of a unit—between 3 of one and 3 of the other $\frac{3}{n}$, and so on.

Example 14—**To construct a scale of $\frac{1}{100}$ to show feet and tenths. (Plate VII., Fig. 3).**

Let the scale be drawn in the ordinary way, but sub-divided throughout its entire length; each sub-division shows one foot; set off to the left on the upper line, a distance equal to 11 sub-divisions commencing from the zero of the scale; divide this into 10 equal parts as in the figure. Since 11 sub-divisions of the plain scale have been divided into 10 equal parts on the vernier scale, each division on the vernier will represent $\frac{11}{10} = 1{\cdot}1$ of the sub-divisions on the plain scale, and as these show feet, each division on the vernier will show 1·1 foot; consequently the several distances from the zero of the scale to the successive divisions on the vernier will show 1·1, 2·2, 3·3, 4·4, 5·5, 6·6, 7·7, 8·8, 9·9 and 11 feet. The scale is used thus.

Let it be required to take off 26·7 feet. Now the seventh division on the vernier will give us a reading of 7·7 on the scale. Subtract 7·7 from 26·7, the remainder is 19; place one point of the compasses on the 19th sub-division on the upper line of the plain scale, and the other on the 7th division of the vernier; this distance represents 26·7 feet.

Vernier scales, when applied to instruments, are constructed so that the vernier can be made to slide on the main scale. In this case it is more convenient if the vernier and scale read the same way, and for this purpose it is necessary to take the $n-1$ units to divide n. The difference is just the same; it is $1 - \frac{n-1}{n} = \frac{1}{n}$ of a unit.

Example 15.—It is required to measure the rise and fall of the mercury in a barometer to the 100th of an inch. (Plate VII., Fig. 4).

The main scale is divided into inches and tenths of inches. For the vernier take 9 sub-divisions and divide this distance into 10 parts.

When the top of the mercury falls between any two of the divisions on the main scale, it is only necessary to slide the zero of the vernier to fit with the top of the column, and read the number of the division that coincides with one of the plain scale. Here the reading is 28·97 inches. The difference between top of mercury, or zero of vernier, and 28·9, is that between 7 divisions on the fixed and 7 on the vernier scale, or $\frac{7}{100}$. If the student will just mark off the divisions of the vernier on a separate slip of paper, and slide this about to fit any different height of mercury, the process will be immediately clear.

Example 16.—Construct a moveable vernier to read minutes to a surveying instrument, of which the arc is graduated to degrees and half degrees. (Plate VII, Fig. 5).

Here the smallest division on the graduated arc is 30 minutes. Take a length of 29 divisions, and divide it into 30 for the vernier. In reading read to nearest half degree, and add the number of minutes shown by the vernier. In this case it is $2° 30' + 11'$, or $20° 41'$.

16. Examples.—1. Construct a scale of $\frac{1}{1760}$ to read to 20 feet.

2. Construct a scale of 8·5 feet to an inch to read to single feet.

3. Construct a scale of metres $\frac{1}{240}$ (1 metre = 1·0936 yards).

4. Finding that the distance between two points on a Swedish map is 7 inches and the real distance on the ground 5,000 alners. Construct a scale of feet (1 alner = ·6493 yards).

5. Construct a scale 22 yards to an inch, on which single yards can be measured.

6. Construct a scale of 6 inches to a mile, showing chains (100 feet).

7. The distance between Roorkee and Saharanpur is 23 miles, and measures on a map 13·67 inches. Draw the scale of the map showing miles and furlongs.

8. Construct a scale of $\frac{1}{33000}$ to show versts (1 verst = 1166·68 yards).

9. On a plan 3·1 inches represent 47 feet. Construct a scale.

10. The plan of a building is square of $3\frac{1}{2}$ inch side, the length of the diagonal represents 100 feet. Construct a scale to read to inches.

11. Draw a scale of miles and furlongs, in which $1\frac{1}{2}$ furlongs equal $\frac{1}{2}$ of an inch.

12. Construct a diagonal scale of 9 inches to a mile to read to furlongs.

13. Construct a scale of 5 miles to an inch and a comparative scale of Russian versts (1 verst = 1166·68 yards).

14. Draw a diagonal scale to read to the thousandth of a foot.

15. A Prussian fathom contains 6 Rhenish feet, each equal to 1·0297 English feet. Construct a scale of fathoms $\frac{1}{234}$ showing feet diagonally.

16. An Englishman, wishing to examine a Spanish plan, finds only a scale of Spanish palms, 20 to an inch; supply him with a corresponding scale of English feet, taking the palm as ·634 of an English foot. Show 50 feet.

17. Draw scales of $\frac{1}{1500}$ to represent English feet, French metres and Greek cubits. 1 metre = 3·27 feet, 1 cubit = ·45 metre.

18. Construct a scale of 6 inches to a mile, to measure furlongs and diagonal spaces of 60 feet.

19. A map is 36 inches long and 30 inches broad, it represents an area of 25 acres; draw the scale of the map to show poles, yards and (diagonally) feet; 4,840 square yards = 1 acre.

20. Required a scale of Russian archines for a plan on which the breadth of a river, really 50 sachines in width, is represented by 12 English inches, 3 archines = 1 sachine = 2·3332 English yards.

21. Construct a scale of 8 inches to 1 mile to read to 20 paces and by a vernier to 5 paces. 1 pace = 30 inches.

22. The distance between two points. 1 Austrian mile apart, is represented on a map by 2·66 English inches. Construct a diagonal scale of English miles. I Austrian mile = 3·3312 English miles.

23. Construct a scale of $\frac{1}{15000}$ to take off intervals of time adapted to the trot of a pony, which goes over 180 yards per minute at a fast trot. Show 10 minutes.

24. A horse passes over about 280 yards per minute at a gallop. Construct a scale of $\frac{1}{20000}$ adapted to time. Show 10 minutes.

25. On a plan 1,200 yards are represented by 15 inches. Draw a comparative scale of French metres (1 metre = 1·0936 yards).

26. The representative fraction of scale on a Russian map is $\frac{1}{1760}$. Draw a comparative scale of French metres (1 metre = 39·37 inches).

27. A distance on a French map which is known to be 3 miles measures 18 inches. Taking a pace to be 32 inches, construct a scale of paces for the map.

28. Construct a vernier scale of $\frac{1}{100}$ to show feet and inches.

29. Construct a scale of $\frac{1}{245}$ to show poles and yards, and by a vernier to read feet.

30. Construct a diagonal scale of $\frac{1}{50}$ to show metres, decimetres and centimetres (1 metre = 3·28 feet).

31. A scale of 4 inches to the mile is attached to a map. On this I find the distance between two points to be 1 mile 5 furlongs. I measure the same distance on the ground and find it to be 1 mile 3 furlongs. Knowing the survey to be correct, construct a correct scale to the map to read to miles and furlongs.

32. Construct a scale of chords and by means of it set off from a line an angle of 75°.

33. One degree on a scale is represented by $\frac{3}{10}$ of an inch. Construct a scale showing degrees and quarter degrees, with a moveable vernier to read minutes.

34. You are given a survey of a portion of country drawn to a scale of 16 inches to a mile. The paper it is on measures 32 inches long by 26 inches broad. Find the area of the country, and the area of paper required to copy the survey to a scale of 12 inches to a mile.

What are the representative fractions of the two scales?

35. A map is 40 inches long and 27 inches broad; it represents an area of 50 square miles. Draw the scale of the map to show miles, furlongs and diagonal chains.

CHAPTER II.

SURVEYING WITH THE CHAIN AND COMPASS.

17. Chain Surveying.—It will simplify the following detailed explanations of the various methods of survey if the student will turn to *Plate* IX, example of a chain survey, and imagine it to represent the real country. Then he will understand that if any straight line, such as *a*, *b*, *c*, *d*, be measured on the ground with a chain, and the distances of the various buildings, etc., etc., measured from it, as we come opposite each, and these measurements recorded in some convenient way in a book or on a rough sketch, then the exact *facsimile* of the country, with all the objects on it near that line, can be drawn to any scale we choose, and a plan prepared such as the example given. To get in any extent of ground, we have only to measure other straight lines like those shown on the plan, passing near all the objects of which we wish to record the positions, and we must also have some means of laying down these other lines, say, *al* and *dl* for example, in correct position with reference to the first line. Thus the survey consists simply in measuring first, straight lines all over the country and recording the measurements of the distances of the various objects from them; and secondly, the positions of the lines with respect to each other. For the first we merely require the measuring chain, for the second we may have an instrument which measures the angles, as *dal* and *adl*, or we may do it by only using the chain and measuring *al* and *dl*, and then constructing the triangle on base *ad*. We can now proceed to describe the various instruments and the methods of using them.

18. The Ranging Rod.—The first item is usually the ranging rod (*Vern. Jhandi*), flag or bannerol as it is called in England. These should be made of straight light bamboo shod with iron at the bottom and provided with a conspicuously coloured flag, usually triangular, of about one foot sides. These rods are most convenient when made 10 feet long, coloured alternately black and white for each foot; they can then be used also as offset rods. When not in use these rods should be hung vertically

from nails driven into a wall, to preserve their straight lines, as it is not possible to range straight lines with crooked rods. These rods are used to mark out straight lines; when the line is short one may be placed at each end, but if the line is long, intermediate ones are required. To place these the surveyor stands exactly behind the flag at one end with his nose close to the bamboo, so that he cannot see the bamboo at all, and looks straight at the flag at the other end; an assistant takes up an intermediate position holding a flag straight up and moves to his right or left as directed by the surveyor, by means of signs and not by shouting, till the flag exactly covers the one at the other end, when by a downward motion of both hands the surveyor notifies the assistant to fix the flag firmly in the ground. It often happens that straight lines have to be run in some convenient direction without a flag at the far end, but the process is very similar, two flags being fixed in the line, the assistant takes his flag beyond them, and is signalled into position by the surveyor at the first flag. The first flag can then be taken up and placed again in line with the two remaining ones further on.

19. The measuring chain is a lineal measure, constructed to suit convenience, of any arbitrary length, and divided into links, each link usually being the $\frac{1}{100}$th of the whole length. For general use a chain of 100 feet, divided into 100 links of one foot each, is the most convenient; for work in the hills one 50 feet long may be used with advantage; but when the sole object is to obtain the acreage *Gunter's chain* is specially adapted, for its length being 66 feet, or four perches, one square chain will represent 16 square perches, *i.e.*, the one-tenth of an acre. A Gunter's chain is also equal to 20 British metres of 39·6 inches. Gunter's chain divided by 11 is equal to 6 feet equals 1 fathom. Gunter's chain divided by 12 is equal to 66 inches = double the Indian "gaz" = 5′ 6″ which is the standard railway gauge for India. Again as Gunter's chain is the integral portion of a mile 10 square chains equal an acre and an inch of water on an acre weighs 100 British (Metric) tons nearly. Lastly a circle with a diameter of 7 yards has a circumference of one Gunter's chain assuming $\pi = \frac{22}{7}$. A standard bigha is $\frac{5}{8}$ths of an acre. A bigha also is an area 55 yards square = 20 "gaz" square.

The measuring chain is usually made of strong iron or steel wire, with a handle at each end, by which it is dragged along the ground. In the 100 feet chain each link is made up by a straight piece of wire about 10 inches long, and by one or more rings, which can be removed or more

inserted at pleasure; these rings also form the connection between the links. To guide the eye in counting the number of links, brass marks are fastened at the end of every tenth link, and distinguished from each other by notches, varying in number according to their position with respect to either extremity of the chain; so that the surveyor can, by simple inspection, readily read any required length. Steel chains are much to be preferred, as they are much stronger and lighter.

Accompanying the chain are 10 arrows, each about 15 inches long and made of iron wire; they are used in succession to mark the chain-length in measuring a line.

The chain is liable to many errors—first, in itself; second, in the method of using it; and third, in the uncertainty of pitching the arrows. Every possible precaution must therefore be used.

If the chain be stretched too right, the rings will give, the arrows incline, and the measured line will be shorter than it really is; on the other hand, if it be not drawn sufficiently tight, the measures obtained will be too long.

If the chain is a new one, it should invariably be measured daily until it has stretched to its utmost; if an old one, which a surveyor will find by experience to be always preferable, once in every three or four days may be sufficient. A careful and correct surveyor will, however, check it daily.

Chains have been known to stretch as much as three inches in a day's work; this though trifling, in one chain, is of material consequence in a day's work of 200 or 300 chains; amounting, as such an error would to about half a chain in the whole distance measured.

To check the length of a chain, the ordinary levelling staff (*see* Chapter VI.) will for general purposes, be sufficiently accurate; two should be used in the following manner:—Stretch the chain moderately tight on a level piece of ground, fixing two stout wooden pegs at each end of the chain; one peg should be firmly driven and marked on the top with a fine tack or a hole made by the point of an arrow, then lay down the two rods from this end, and keeping the second stationary, take up the first, place it beyond the second, then keeping that stationary, take up the second and placed it beyond the third, until the end of the chain be reached, when the second peg may be driven and marked in the same manner at 100 feet or whatever length the chain is required to be. The chain should now be stretched between these two pegs, and its length corrected, if necessary, by adding or removing rings. A good steel tape, kept for checking purposes, will be found more satisfactory.

20. How to use the chain.—In using the chain two men are required, one called the "forward man" who drags the chain forward, the other called the "chainman." The movements of the forward man are directed by the chainman; it devolves upon him to keep the forward man in the true line, to see that the chain is properly stretched, no links in it, etc. Before a line can be measured, its direction must first be clearly laid down by means of flags. A flag is placed upright at each end of the line, and if the line is very long, intermediate flags must be placed so that the chained line may not deviate from the line required. This is called "ranging" the line. In measuring the line the chainman stands at the starting flag and places his end of the chain in contact with it, while the forward man to whom all the 10 arrows have been given, proceeds with the other end of the chain in the desired direction until it becomes nearly extended. The forward man then squats on the ground, and the chainman directs him to one side or other till the arrow he holds upright in his right hand in contact with the outside of the chain handle is in line with the far flag. A great deal of time is saved if the forward man is instructed to also align the chainman with the back flag; very often the forward flag is lost to view and then this is essential. The chain is now lifted partially from the ground, and the chainman seeing that it is in the right direction, gives the motion *down* to the forward man. The forward man then, keeping a firm pull on the chain, presses the arrow with his left hand firmly into the ground. They then proceed to the next chain-length, and so on.

The surveyor if not the chainman, should keep a continual watch over the chainman, and to do this his position must be just in rear of the chain. He must insist that the chainman brings his end of the chain up to the arrow in the ground, and that the forward man after getting in line and stretching the chain, puts his arrow firmly into the ground at the proper point. Strictly speaking a chain should be the thickness of one arrow less than its nominal length, otherwise the thickness of an arrow is gained in every measurement, which, when the distance measured is great, would amount to something considerable. If the ground is too hard to admit of the arrow being driven in, a cross should be scratched upon the ground, and the arrow laid down pointing to the intersection. In starting for a new length the forward man should give the chain a throw to one side so as to clear it from the arrow as it is dragged along.

After the forward man has fixed his last, the tenth arrow, he proceeds another chain's length; now, however, he has no more arrows

so immediately on getting into line and stretching the chain, he must put his foot on his end, or otherwise securely hold it, when the chainman brings up the arrows, fixes one into position at the end of the chain and gives the balance of 9 arrows to the forward man to continue the measuring. The great objection to this arrangement is that during the exchange there is nothing in the ground marking the distance measured, and to remedy this some surveyors use eleven arrows, never taking into account the one arrow which is always in the ground at one or other end of the chain. But the eleventh arrow will creep into the tally unless the surveyor is constantly on the look-out; and consequently, attention to the arrows is added to the list of things to be kept in mind, whereas in the former case it is purely mechanical. Again the mere act of changing calls the attention of the surveyor to the fact that another length of ten chains has been measured, and he notes it accordingly.

21. Surveying by the chain only.—This method of surveying is very slow but accurate, and is chiefly used for plans required on a large scale, such as maps of estates, etc., whose boundaries have to be carefully delineated. It is not suitable in a country where many obstacles impede the view or render horizontal measurement difficult. The plant required is very inexpensive,—a chain, an off-set rod* and a few flag-poles being all that is necessary.

In making a survey with the chain only, we are confined to one, and the simplest geometrical figure, *viz.*, the triangle; for of all plane geometrical figures, it is the only one† of which the form cannot be altered, if the sides remain constant. The surface to be measured is therefore to be divided into a series of triangles; and in this division it must be borne in mind that the triangles are to be as large, with reference to the whole surface to be measured, as is consistent with the nature of the ground; for, by such an arrangement, we are acting on the important principle in all surveying operations, that it is well always to work from *whole* to *part*, and rarely from *part* to *whole.*

The sides of these triangles are first measured, and as a necessary check on this part of the work, a straight line is in addition measured from one of the vertices to a point in or near the middle of the opposite side. This fourth line is called a tie line, and is an efficient means of detecting errors, if any have been committed in the measurement of the

* A tape is preferable for taking off-sets.

† Euclid, I; 7.

sides of the triangle. This fourth measurement is made in accordance with a maxim which ought invariably to be acted upon in all survey operations, *viz.*, **that where accuracy is aimed at, the dimensions of the main lines, and the positions of the most important objects, should be ascertained or tested by at least two processes independent one of the other.** Within the larger triangles, as many tie-lines and smaller triangles are to be measured as may be necessary to determine the position of all the objects embraced in the survey. The directions of the lines forming the sides of these secondary triangles are so selected or disposed that they shall pass close by as many objects as possible, so that the off-sets to be measured from them may be as short and as few in number as practicable.

22. Hand sketch.—The disposition and general combination of these triangles demanding care and judgment, it is customary, previous to commencing any measurement, to walk over the ground for the purpose of obtaining a general knowledge of the surface, and of the relative positions of the most conspicuous objects. The acquisition of this knowledge, depending on the *coup d'œil*, is much assisted by an eye-sketch drawn with rapidity, and showing some of the principal roads, streams, temples, etc.

This hand-sketch is not drawn to any scale, and its object is attained if it simply bear a general resemblance to a plan of the ground, as it will thereby assist the memory in the distribution of the surface into triangles. It should invariably contain a North point, showing the direction of the meridian.

The hand-sketch, or rough diagram, is usually made in a Field-book, *i.e.*, a book in which every minute step of the operations gone through is to be entered accurately in ink at the time. The after operations of plotting the survey from the Field-book are made very much simpler, if the positions of the measured lines and the stations be also shown in the rough sketch. Field books must be properly indexed with cross references when necessary. The index to appear in the first page of the book.

The sides of the larger triangles must pass as close as possible to the external boundaries to be surveyed; the triangles should, moreover, be made to approach, as nearly as practicable to the equilateral form, avoiding with care very acute or very obtuse angles, because the further the form of the triangle is removed from the equilateral, the greater will be the alteration in the form of the figure and its area, should an error have been committed in the measurement of any one of the sides.

The triangles having thus been disposed to the greatest advantage, marks or pegs are placed in the ground at each vertex of the triangles; the general form or position is then noted on the hand-sketch previously made, and distinctive letters or numbers are written on the diagram at each point of intersection; this arrangement admits of easy reference in the Field-book, or on the ground, to any triangle or part of a triangle.

23. The method of finding direction of meridian by the sun's shadow is as follows.—Drive a stake having a pointed top, into the ground. Plumb it carefully so that it be quite vertical; mark where the sun's shadow is thrown, and with about that length as radius, describe upon the ground, with the stake as their common centre, two or three circles with slightly different radii. Watch the shadow of the top-point of the stake, and note where it touches the circumference of the larger circle, before noon and also after noon. Do this with the other circles; connect these points upon the circumference with the centre, and bisect the angles; these should have a common bisection. Should this not be the case, the mean may be safely taken provided the difference between them is not great. This bisector is the true North and South line: if now a compass be set up on the line and the bearing of a line read, that reading will be the variation of the compass at that point.

24 Station points.—The points of intersection of all straight lines, as well as the vertices of triangles, are always points measured *to* or *from*; they are called *station points*, and the lines connecting them, station lines, thereby distinguishing them from the simple off-set lines.

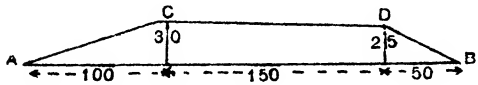
Whenever the station points occur along the various chain lines, a mark must be left in the ground at each station for future reference. In an extensive survey, the mark must be more or less permanent. In grass land a small peg driven into the ground at the station point, and surrounded or pointed at by some simple geometrical figure cut in the grass is sufficiently permanent; but in arable lands, there is no other way than driving in a good stout peg, and even that is liable to removal or to be ploughed up.

Stations are expressed in many different ways, either by letters or by the numerals, or by the numbers which represent the length of the line just measured. This last method, although often adopted by surveyors, is very confusing to the beginner; he should learn by lettering his stations, or if he thinks that he will have more stations than there are letters, let him use the numerals.

The position of each station should be fixed by, at least, two independent measurements to permanent objects. A nail driven flush into the trunk of a tree gives a good point to measure from.

25 Off-sets are short perpendiculars, measured from a station line to the angles of a crooked or zigzag line near which the straight line runs, or to all objects which it is desired to represent on the plan.

Fig. 13

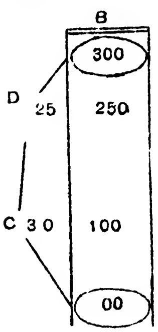


Thus, in the figure, let ACDB (*Fig.* 13) be a crooked fence bounding one side of a field. Chain along the straight line AB, which runs from one end of the fence to the other, and when opposite each corner, note the distance from the beginning, or the point A, and also measure and note the perpendicular distance of each corner C and D from the line.

The field notes corresponding to the above figure would be written as in *Fig.* 14. The measurements along the chained line are written in the centre column, each one counting from the beginning of the line, and the off-sets are written beside them, on the right or left as the case may be, opposite the distance at which they are taken. A sketch of the crooked line is also added in the field-book.

Short off-sets are best measured by means of a rod, called an *off-set rod*, which is usually 10 feet in length but for longer off-sets the 100′ tape is recommended. When the objects are situated near the chain line it is easy to find from where the off-set springs, but when the off-set is of some length, say 80 or 100 feet long it is not so easy to judge where the right angle would be. In such cases the eye is very much assisted by laying the off-set rod across the chain, as nearly at right angles as can be judged ; if its prolongation does not pass through the object, it must be shifted along the chain until it does. A second trial will always be sufficient to find the exact place. An instrument used for laying out right angles and called an optical square is sometimes used. With a tape the point at which the distance from the object to the chain is the least gives the correct chainage for the off-set.

Fig. 14.



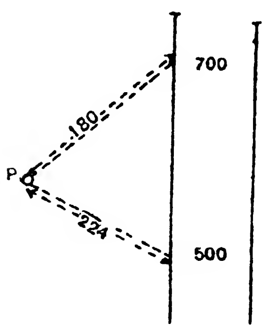
Off-sets must be taken sufficiently often to ensure the accurate plotting of the work on paper, but a little consideration will often obviate much unnecessary work and reduce to a minimum the number of off-sets

whose measurement is actually required. For instance, in running a chain line along or near a made road it is quite unnecessary to read off-sets to both sides of the road and also to the hedges and ditches which may bound the road; it is quite sufficient to read an off-set to the side or centre of the road, and only occasionally measure the width of the road with the corresponding distances to its bounding hedges and ditches, unless marked changes in the widths occur. Again, the number of off-sets is largely dependent on the scale to which the survey is to be plotted; if, therefore, the scale of the plan is too small to admit of roads or drains, etc., being shown except by the conventional signs in use, it is useless to take off-sets except to the centre of the road or drain.

Off-sets longer than 100 to 150 feet should never be admitted in a chain survey having any pretensions to accuracy. The lines to be chained must be so adapted that no such long off-set will be necessary, or, if the main lines cannot be changed, smaller triangles must be built on them, and so prevent the necessity of long off-sets.

If the position of a solitary object is required, and it is too far to admit of an off-set to be taken to it, its position can be accurately determined thus:—Suppose P (*Fig.* 15) is some isolated object, and it is opposite some point 600 in the chain line, and about 2 chains distant. When the arrow denoting 500 has been fixed, measure the distance from the arrow to the object P, and enter it as shown in the diagram. Then continue chaining the original line until the 700 arrow is fixed. then again measure the distance from the arrow at 700 to P, and enter it in a similar manner. The point P can now be accurately placed on paper with reference to the chained line. Care should be taken that P should form the apex of a triangle as nearly equilateral as the eye can judge.

Fig. 15.



26. The Field Book should be of a convenient size for the pocket having each page ruled with a central column, which is about five-eighths to one inch breadth. The entries are always made commencing at the bottom of the page, the surveyor walking along the line looking at the front

flag, as then the page becomes a small, though distorted, representation of the reality. Were the entries made from the top downwards, the Field-book would then represent the reverse of the reality.

In keeping the Field-book, it should ever be remembered that the central column is virtually but *one* line representing the chain, the space within the column being merely required for the several distances on the chain, whence the off-sets are taken; and also, that all off-sets read either way *outwards* from the centre column, in the same way as they have measured *outwards* from the chain; if the station line, therefore, should be crossed on the ground by a road or any boundary meeting it obliquely, its representation in the Field-book must not be made to pass obliquely across the middle column, but must arrive at one side of the column and leave it at the other, at points precisely opposite, as it would do were the middle column merely the thickness of a line: inattention in this particular, causes much confusion in the relative position of off-sets.

The entries must be made in ink and corrections must be made in ink initialled and dated. The pages should also be numbered for facility of reference, headed with the name of the lines of which the page contains the survey, and each day's work dated. Names, numbers, figures, etc., can be neatly entered in the style shown in Plate IV*a*.

In a Field-book it is a saving of labour to call each combination of two pages, as it lies open, one page.

The Field-book should contain no erasures of any kind. Should it be necessary to correct an entry, it must be done by drawing the pen through the original entry, and writing the correction above it.

Writing down the chainage, *i.e.*, the distance measured, in the central column of the Field-book, is at first a little puzzling. The surveyor should always enquire from the chainman the number of arrows he has in his hand to find out the distance, he should never ask the forward-man unless it be to satisfy himself that none of the arrows have been dropped. Suppose that an off-set 25 feet long, falls on the 50 mark of the first chain measured, then in the central column 50 is written, and to the right or left, as the case may be, the off-set 25 is placed. Let another off-set fall at 47 links on the chain, the chainman holding 6 arrows in his hand, the chainage will then read 647; after the first change of arrows say that the line crosses a ditch at 79, the "chainman" holding 3 arrows the chainage then will be 1379; if this had occurred after the 5th change, the chainage would have been 5379, and so on; hence the necessity of entering

the chainage each time a change of arrows occurs, as it denotes that 1000 links or 10 chains have been measured ; if this is neglected, a length of 10 chains is very apt to be left out, and particularly so when few off-sets are taken. When chaining very long lines, it is advisable to enter each 1000 feet in brackets, thus—(1), (2), (3), and make the off-set entries in hundreds and feet only.

The usual error beginners make is to write too small figures and close together, plenty of room should be taken. When off-sets are to be taken to a complicated object, say the building at top of example of Field-book, it should be sketched in first, and the distances written in afterwards, opposite its points : there is no object in having the distance entries at even distances on the paper. This is done in all but the first page of the example to save space in printing. The first page is the real specimen. Another point to which the attention of beginners is directed is that they should carefully consider by what off-sets the position of a house or any feature of ground can be most accurately determined. For example, in the case of the large pucca house at the top of page 1 of the example, the off-sets 129 and 93 from points 320 and 404 of the chain line are much more important than the off-sets 93 and 118 from points 404 and 412. The important off-sets of any particular feature can only be determined by careful consideration and practice.

Figures denoting dimensions of details of plans of buildings should be used as sparingly as possible, and should invariably be included between arrow heads as in draughtman's work, to prevent their being confused with figures denoting off-sets, which latter should always be written close against the points to which they refer, and not midway between the point and the chain line.

No Field-book is complete unless it contains at the beginning of the work an index showing on what pages the detailed survey of any particular line may be found.

27. Scale of plan.—Before commencing actual measurements in the field the scale of the plan, or in other words, the degree of accuracy, should be considered. One-hundredth of an inch is about the smallest length that can be shown on paper, so if the scale is to be 100 feet to an inch or larger, the chainage and off-set must be read accurately to the nearest foot ; whereas if the scale was to be 500 feet to an inch, no distance under 5 feet in length would be perceptible on the plan. These considerations deter-

mine the number of off-sets required, for the larger the scale, the greater the detail that can be shown.

It cannot be too strongly impressed on the surveyor that the work which he is called upon to perform depends for its accuracy in a very great measure on the neatness, order and system bestowed on all the steps whether of delineation or measurement: proper attention in keeping the Field-book saves much time in plotting, and guards against the errors unavoidably arising from reference to a confused Field-book; moreover, care bestowed in the first essays, will amply reward the surveyor, by giving accuracy of eye, freedom and steadiness of hand; qualities indispensable to his success.

28. Specimen of Field-book and Plan.—A specimen is here given of a Field-book, *Plate* VIII, and the plan made from it, as an example of a chain survey, *Plate* IX. The ground was walked over first of all, and a rough sketch was made showing nearly the position of the river, its two bridges, the village, jhil, church, etc. This gave a good idea as to the disposition of the necessary lines which would have to be measured.

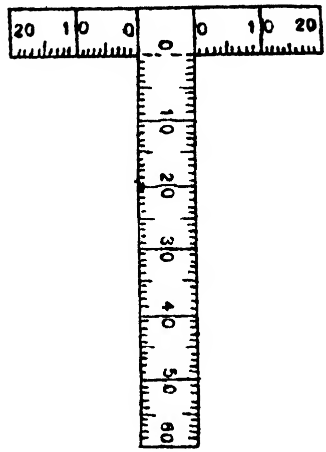
The line *a*, *d*, *g*, was first measured, and off-sets taken to everything which was required to be shown on the plan; *b*, *c*, *d*, *e*, and *f* were intermediate stations left on the line from which to run cross or tie-lines, or else from which to fix on other triangles. Then the lines *dl* and *la* were measured, and *h* and *k* in the former and *m* in the latter were left as intermediate stations; then the cross lines *ch*, *bk*, *mt*, were chained to enable off-sets to be taken to the objects in the middle of the triangle, and also to serve as check lines when plotting the survey.

The cross lines may be left until the sides of all the principal triangles are measured, and then each triangle may be filled in afterwards, but the points in the main line from which it is intended to run them must be marked at the time of measuring the sides of the principal triangles, or a great deal of unnecessary measurement will be entailed. Thus are all the sides of triangles measured in succession, and their dimensions with the additional assistance of the off-sets, give the means of ascertaining all the boundaries, external, and internal positions of houses, etc., and of finding the area of the whole and of every part, by direct computation from the Field-book.

29. Plotting the Survey.—The method of plotting a chain survey is so self-evident that a few words of explanation will suffice. In the above example, lay down on paper a line equal to *ad*, taken from any scale of

equal parts from the same scale take the length *al* with a pair of compasses, and with this as a radius and *a* as a centre, describe an arc; now, taking *ld* as a radius and *d* as a centre, describe an arc, cutting the first, their intersection will give station *l*. In the same way lay down the triangles *lna* and *adv*. Now commence with *ad*, and mark off the distances given in the centre column of the Field-book, at the same time setting off the off-sets; for this purpose a small cardboard or paper scale, of the shape shown in *Fig.* 17, will be found very useful; by means of the middle scale either of the short arms can be placed at the required distance from the station and the off-sets marked from them. In the same way proceed with the sides *al*, and then fill in the triangle by means of the cross lines *ch* and *bk*. Proceed with the other triangles in a similar manner until the whole is completed.

Fig. 17.



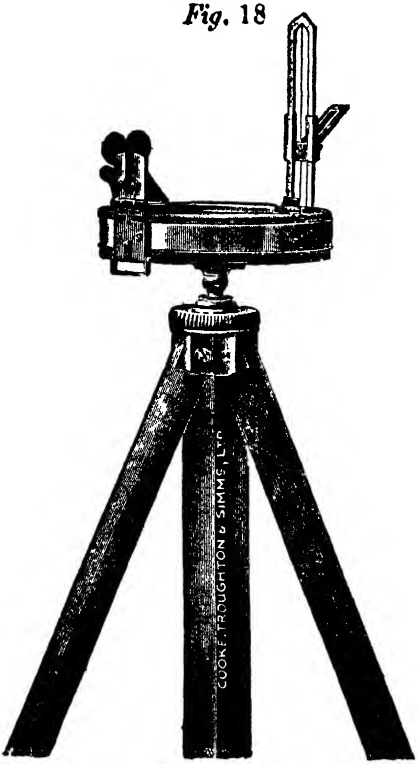
When using engineer's scales and off-sets the scales should be so placed parallel to the main line and even pinned down with two drawing pins placed over its extremities so that the centre line of the off-set will slide correctly along the main line. This is the most effective way of using the engineer's plotting scales.

30. Chain Survey Practice.—It is useful practice to take any plan, and treat it as real ground; lay down and measure lines on it, and off-sets from them to the objects shown, and make out a complete Field-book from it. Then putting away the plan, plot the Field-book on a fresh sheet of paper, and compare the result with the original. The student can note omissions in the Field-book and learn the routine very easily in this way, and will start on the actual survey with more confidence. He should also learn where great care is necessary, as in chaining main lines, and where approximations can be safely made as in taking off-sets to unimportant buildings or to features of ground the outlines of which are not clearly defined. Always bear in mind that the Field-book should be made out in such a way as to allow of its being plotted by some different person who had never been over the ground surveyed. To this end the hand-sketch referred to on page 42 and the index referred to on

page 47 should never be omitted, and cross-references should be made wherever possible, *i.e.*, should any house or feature of ground or station occurring in a page of a Field-book have occurred previously in a former page, cross references to the two pages should be made. It is only by a constant regard to clearness and conciseness that the isolated field observations of the surveyor can be knit into an accurate whole.

31. Bearings and Angles.—Before proceeding to describe the methods of Surveying with 'angular instruments,' it is as well to understand at first the difference between *bearings* and *angles*. Euclid's definition of an angle is, "the inclination of two lines to one another;" the prismatic compass, however, does not show this inclination, but only shows how the line from the object to the observer is inclined, or *bears* to the magnetic meridian. Therefore, to find the angle subtended at the observer's eye between two objects with the prismatic compass or Surveyor's compass, it is necessary first to find the *bearings* of the two objects, *i.e.*, the angles they make with the magnetic meridian, and take the difference between these two readings, to get the angle. The Theodolite reads these angles directly.

Fig. 18



Horizontal angles between the geographical meridian and lines from observed objects to the observer are known as *azimuths*, or sometimes "true bearings." Azimuths are inclinations from true North (or South) and are therefore to do with the earth's centre. Bearings are inclinations to some certain adopted meridian as in traversing and thus are to do with the earth's surface. Inclinations from magnetic North should invariably be called *magnetic* bearings and not simply bearings.

32 Prismatic Compass.—The Prismatic Compass consists of a circular brass box in the centre of which is a metal point. On this metal point is balanced a magnetic needle which carries a circular disc of aluminium. This circular disc is divided into 360 degrees the degrees being further sub-

divided into half degrees. The magnetic needle is fixed on the line 0°, 180°. At the centre of the needle is let in a little agate cap which fits on the metal point in the box and thus leaves the needle carrying the circular graduated rim free to revolve, so that when at rest the 0°—180° line of the graduated rim will always point to magnetic north. On the circular box at one end is mounted a prism which enables the figures on the graduated rim to be read. Diametrically opposite to the prism is fixed the sight vane and by means of the slit on the top of the prism and the horse-hair in the vane the instrument is aligned on any object. The prism and sight vane are both hinged so as to fold down for putting away in the case; the latter folds flat over the glass covering the top of the box and at the same time actuates a stop which lifts the magnetic needle off its seating and so minimises wear of the metal point, as upon the fineness of this point much of the swing and accuracy of the instrument depends. Below the hinged joint of the sight vane is a stud actuated by a spring, which on being pressed impinges against the graduated rim and so brings the needle to rest.

It will be noticed when examining the graduated rim that the zero division is placed at the South end of the needle and that the 90° and 270° divisions are placed on the West and East sides of the needle respectively. The reason for this is that the prismatic arrangement for reading is placed on the opposite side of the compass to the object to which a reading is being taken, hence with a reading to an object which is due East, the prism will be on the West side of the needle and it is at that point subtending a bearing of 90°.

A prismatic compass can be adjusted to read a certain inclination to north by shifting the magnetised bar underneath the ring, but in modern instruments some special arrangement is provided for altering the readings so as to allow for the local variation of the compass. By the aid of the Prismatic Compass horizontal angles can be measured to within about one quarter of a degree. It is particularly useful in filling in the details of a survey, for sketching along a road or river, and is, in conjunction with the abney level, an invaluable instrument for reconnaissance. The compass is often held in the hand when the bearing of any object is taken, but much greater accuracy can be obtained by placing it on a stand.

The divisions in some instruments are numbered from 0° to 180° south counting eastward, and thence to 180° north counting westward others are numbered 5°, 15°, etc., round the circle to 360°, 90° representing

east, 180° south, 270° west and 360° north. These latter are by far the best as the least liable to error in recording the results in a Field-book and are more generally understood by Indians.

This instrument must be set up as nearly horizontal as possible in order that the card may play freely; also it must not be used near iron, or by a surveyor wearing steel rimmed spectacles.

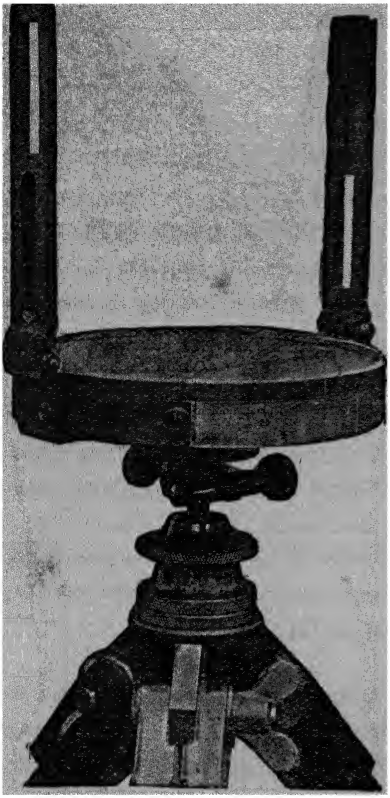
The meridian line given by any magnetic needle differs from the "true" or "geographical" meridian by an amount which is known as the magnetic variation. The compass variation will generally be found to differ slightly in different compasses, although nearly alike for compasses used in the same district. The slight difference is due to the zero line of the compass ring not coinciding exactly with the axis of the magnetic needle. In order that the work of several survey parties may be successfully combined, however, it is necessary that the "variation" of each compass be known and allowance made for it in plotting bearings.

Variation is said to be east or west according as the magnetic meridian lies to the east or the west of the geographical meridian, and methods of finding its amount are given in Part II of this Manual.

33. The Surveying Compass.—The surveying compass consists of a compass-box, magnetic needle, and two plain sights perpendicular to the meridian line in the box, one of which has a longitudinal slit through which the surveyor aligns the horse hair onto the object of which the bearing is required; it is used for the same purpose as the prismatic compass, for filling in the interior detail of a survey by means of bearings, but is so inferior to that instrument that surveyors now never use it.

There is one peculiarity connected with this instrument and, indeed, with all compasses in which the magnetic needle swings freely over a fixed card, that the east and west points of the horizon appear to have changed places. In the prismatic compass the graduated arc is attached to the needle, and consequently is always stationary; the

Fig. 19.



bearing of any object therefore is the same angle as that through which the *sights* have moved from the meridian. In the surveying compass, the card and sights are fixed and so move together, the bearing of any object then is the same angle as that through which the *card* has moved. For instance, say an object bears 90° east; that is at once read off by the prismatic compass, but in the surveying compass the north point of the card is now pointing towards the object, and the west point of the card is now under the north point of the needle.

The reason for changing the position of the words now is obvious; for were they not changed, the observer would read the bearing as 90° *West* (seeing the word west under the needle), thus reading a bearing diametrically opposed to the reality.

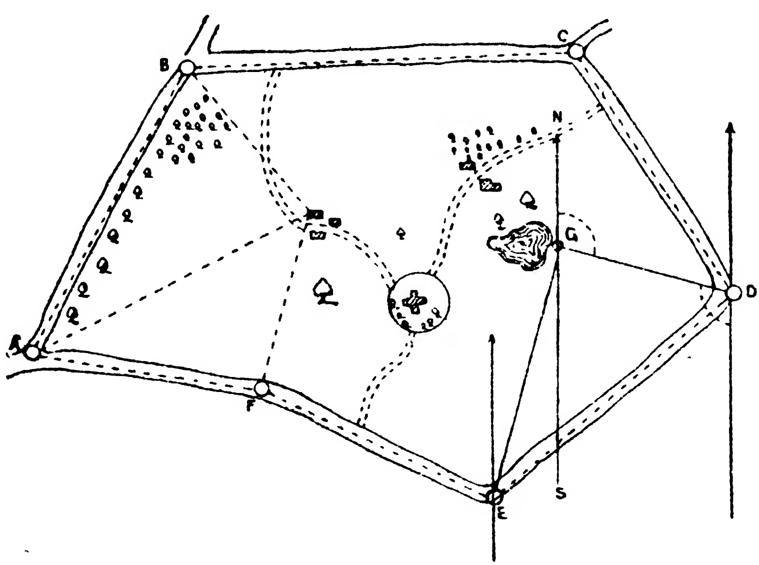
34. Method of Surveying with the Prismatic or Surveying Compass—This only differs from that described for chain surveying in that the bearings of the straight lines from which off-sets to the various objects are taken can now be measured, and therefore these can be plotted from the north line, and there is no necessity for cutting up the survey into triangles as before. Also bearings can be taken from two or three points to distant objects, as the block of buildings in the example, which is fixed by the intersection of bearings from A, B and F, and thus the necessity of running a line near enough to it to take off-sets is avoided.

Let the annexed plan (*Fig.* 20) represent a survey of roads to be performed by the prismatic or surveying compass. All preliminaries of making a hand sketch and selecting stations for a chain survey having been completed set up the compass at A, and send a man with a flag-staff to B.

Now take the bearing of B, and proceed to chain from A to B, taking offsets to the sides of the road and any remarkable objects, precisely as in a chain survey. Having arrived at B, the compass must be again set up, and a flag-staff having been set to C, its bearing must be obtained; then the line BC is to be measured, and so on. Bearings must also be taken to any conspicuous objects that are out of reach of an off-set, such as the corner of the house in the figure; readings from two points are sufficient to fix it but a third should be taken as a check.

Surveying with the compass is more convenient where the ground to be surveyed is a large open tract with a few isolated important features, or where long straight lines and convenient ties or triangles cannot be made on account of obstructions, but it is more liable to error, as the compass is often sluggish and the needle does not swing exactly to the true north, and, therefore, care should be taken to check the work by measured

Fig. 20.



cross-ties as much as possible to avoid having to do the detail work over again.

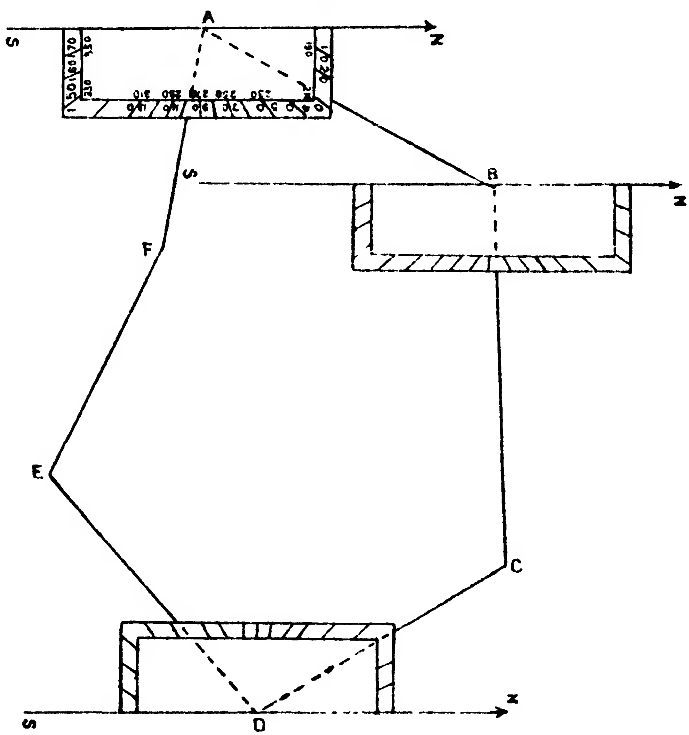
When surveying a large area, the main framework of lines, as sketch, *Plate* IX., should be entrusted to the most experienced or accurate worker of the party, inferior men can then fill in the details between the points so fixed, and this main framework should be plotted to avoid possible waste of labour.

Where the area to be surveyed is covered with close detail, which it is required to plot to a large scale, as in the case of a cantonment or town, a combination of both chain and compass survey is generally the most suitable rapid method by which it can be carried out. The ground should first be gone over with a view to choosing the positions on the main circuit as in compass survey and a hand-sketch made as described in para. 22. It should then be noted on the hand-sketch what tie-lines, run between points on the main circuit, will sub-divide the area most conveniently. These secondary stations on the main circuit are known as tie-line stations, and it will probably be necessary to run minor tie-lines between points on these main tie-lines until the whole of the detail is brought within reach of the off-set rod. This form of survey differs from the ordinary Chain Survey described in para. 21 only in the fact of it not being absolutely necessary to work in triangles, but it should be borne in mind in this as in all other survey work that the triangle is the only safe figure to work with, as it is the only one whose sides do not admit of distortion when their lengths are known, and whenever possible the work should be carried out in triangles. It will be found to save confusion if the stations of the main circuit be denoted by Roman capital letters, the primary tie-line stations by italic letters, and the minor tie-stations by numerals.

35. The Field-Book is kept as in the chain survey, the only addition being the bearings. The bearing to the next forward station is called the "forward bearing;" this should be written in the centre column immediately above station No. 1. It is only *necessary* to take bearings from every other station—for instance, we might go to B, (*Fig.* 20) and from there observe the bearings of both BA and BC, then to D, and observe DC and DE ; but it is advisable to take readings at every station, for it prevents confusion in the field-book, and also the trouble of adding or subtracting 180° from every second reading, which in the other case would be necessary before the work could be plotted. To ensure accuracy and to check the vagaries of an indifferent compass, or to detect errors in reading, it is always well to read both the *forward* and *back* bearings at each station. The previous "forward" and the new "back" bearing should differ by 180° ; if the divergence is slight, *i.e.*, up to one-quarter degree, the mean should be used, but if great, the work cannot be depended upon, as the compass must be out of order, or else one of the bearings must have been read incorrectly.

36. To plot the Survey (*Fig.* 21).—Having fixed on a convenient spot on the paper for the starting point A (*i.e.*, so that the survey may be contained in the paper, and as nearly in the middle as possible), draw a line through it to represent the magnetic meridian, place the protractor to the right of this line, the edge coinciding with it, and the centre at the point A; now, with a pencil mark the required angle, and draw a line through this point and A, this will represent the first bearing; on this line, produced if necessary, set off from any scale of equal parts, the length of AB, and through B draw the line NBS parallel to NAS to represent another meridian, and placing the protractor as before, lay off the angle NBC; set off BC the required length; and proceed with each angle in the same way until the end of the line FA should coincide with the starting point A. If an angle greater than 180° is required to be set off, the protractor must be placed to the left of the meridian, as at D and the second row of figures used. In projecting the circuit, in order to get good results, the longest setting by the protractor on the given meridian is advisable. Having completed

Fig. 21.



the circuit and corrected it if necessary (*see* paragraph 38) the off-sets can then be plotted in the same manner as in the chain survey.

37. Use of circular protractor.—Another method of plotting a survey of this kind is with the large *circular card protractors* generally used, the better plan is to plot a number of bearings from the same point, and rule the actual lines required parallel to the lines so dotted of. Thus, in example, all the bearings might be laid down from the first position of the protractor at A by dots at say *b*, *c*, *d*, etc., and BC, CD′, DE, etc., ruled parallel to A*c*, A*d*, A*e*, etc. This plan avoids the possible error in replacing the protractor each time. The protractor, it will be noticed, when placed correctly on the plan, is really the same as the graduated circle of the compass, and the lines marked off are the various position of the sights of the compass.

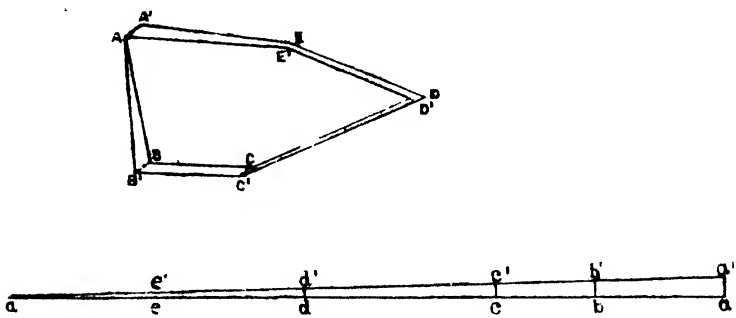
The *circular card protractor* can also be used as follows to plot the bearings of a traverse. The plain centre portion should be cut out to within half an inch all round of the degree divisions, then place the protractor on a meridian as before described with the point from which the bearing is to be drawn lying inside the cut out portion. Now place a brass parallel ruler on the protractor, with one edge on the fore and the other end on the back bearing of the line, and run it up to the point from which it is desired to plot the bearing—the method will be found very expeditious and accurate when plotting a traverse of short lines with varying bearings.

Should it be required, for the sake of uniformity, to plot the survey with the true north running up and down the paper instead of the magnetic meridian, a line representing the true meridian is first marked on the paper, the protractor is then laid over this line so that the graduation representing the variation is along this line. The zero of graduation having been thus moved round through the amount of the "variation," all bearings plotted with regard to it will have been laid off with their correct azimuths from the geographical meridian.

38 Correction of closing error.—In plotting a chain survey by means of protractors it is impossible to get the angles perfectly accurate. Not only this but with a prismatic compass absolute accuracy is unattainable and in plotting work of this nature we shall as a rule find a closing,

error, *i.e.*, the circuit as shown on the plan will not close. To adjust the error, all round the survey the following method is used :—

Fig. 22.



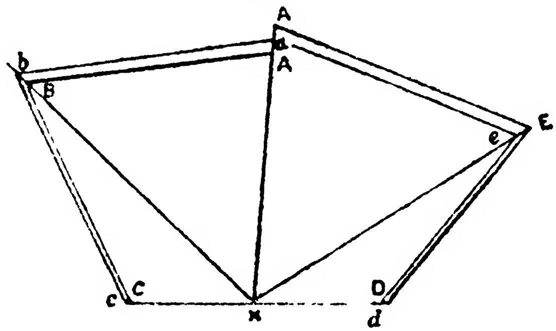
Suppose a traverse A B C D E A has to be plotted (Fig. 22) and on completing the circuit we find that the last line EA falls as shown by EA′ in the above figure thus not closing the traverse. To close the traverse join AA′ and through each angle of the plot draw lines, parallel to AA′. Now draw a line aa' equal or proportional to the length of the circuit and divide it up into lengths equal to or proportional to the sides as shown above. Through a draw $a\ p$ perpendicular to aa' and ap equal to or proportional to the closing error AA′. Join $a'p$ and from the points b,c, d,e, erect perpendiculars to meet the line $a'p$. Now from B along the line drawn parallel to AA′ set off BB′ equal to bb'. From the other points carrying out the same construction making CC $=$ cc' etc., join AB′, BC′, C D′, D′E′ and E′A thus closing the figure. This is only permissible when the closing error is less than 1 in 300 otherwise the detail when plotted will be distorted.

Note.—If instead of making $aa' =$ to the perimeter we made it ¼ or ⅛ the perimeter then ap would be made ¼ or ⅛ of AA′. Hence bb, cc', etc., would be ¼ or ⅛ of the real correction required.

An alternative method by which the sides of the polygon are corrected to meet the case of closing it and leaving the angles or bearings unaltered is here given.

Let a circuit start at A and go to B C D E and have A'A as the error. Join these two points and produce the line to meet one side of the polygon

Fig. 23.



at X. Join BX and XE and through *a* the middle point of AA' draw lines *ab*, *bc*, *ae*, *ed* parallel respectively to AB, BC, AE and ED, *a b c d e* will be the corrected polygon.

39. Filling in detail.—The prismatic compass is very useful for what is called filling in a survey. The plotting of this kind of work is usually done in the field, each angle being laid down as soon as taken, and each distance and off-set as soon as measured, so that no field-book is required. A piece of paper with the work already done, such as the above circuit of road plotted on it, is placed in a sketching case, and faint parallel lines are ruled over it in a direction at right angles to the meridian, at unequal distances apart, varying from a quarter to half an inch; then, when a bearing is taken, the protractor is placed at right angles to these lines, and the angle at once marked off.

40. Finding one's place in a Survey.—The following method of finding one's place in a survey with the prismatic compass will be found useful. Referring to *Fig.* 20, suppose it is desirable to star the filling in from a point G near the tank, and not from any of the former stations the first thing is to find the position of the point G on the plan; to do this, it is only necessary to stand on the spot, and from there take the bearings of any two convenient stations, in this case D and E; and to protract the angles thus obtained from D and E—their intersection will be the point required. For instance, the bearings of D and E from G are found to be 100° and 205° respectively. Placing a protractor at D and E, plot these bearings, and their intersection gives the point G; of course they must be ruled backwards from D and E, or 180° may be added or subtracted as need be. It will be as well to take a bearing to a third station as a check. Observe that the nearer the two bearings intersect at a right angle, the more accurately will the station be determined.

CHAPTER III.

INSTRUMENTS, THEIR USE AND ADJUSTMENTS.

41. The spirit level or level bubble consists of a glass tube the inside of which is ground to an arc of a circle* and it should be so mounted that the axis of the bubble is parallel to the line of sight. The Y-level is fitted with two screws to control this adjustment. The radius of the arc of this circle is large or small according to the degree of sensitiveness of the bubble. The grinding of the tube must be even, so that the travel of the bubble will be uniform. The tube is very nearly filled with ether and it is then sealed and the air which remains becomes a bubble and always moves towards the highest point of the arc. The length of the air space should be about 2 inches at a temperature of 86°F. The size of the bubble varies with the temperature, the bubble contracting under heat and in the middle of the day is sometimes half the length it was in the morning. Some tubes are fitted with air chambers so that the size of the bubble can be regulated.

The more sensitive a bubble is the more accurate the work, but this holds good only within certain limits since the pitch of screws, quality of lenses in the telescope, graduation of verniers, all rule the limit of sensitiveness of the bubble. A sluggish bubble for reasons given above may also be useless.

The bubble tube is generally graduated and marked in tenths of an inch from the centre outwards and the sensitiveness of the bubble is known by its angular value for one division of arc of the bubble. Levels should have bubbles with a sensitiveness of 20 to 12 secs. according to size, and theodolites with a graduation and verniers reading to 20 secs., of about 10 secs. for upper plate and 20 to 25 secs. for lower plate levels.

The axis of the bubble tube is the line tangent to the bubble arc at its middle point and when the bubble is in the "centre of its run" as it is termed this tangent line is a horizontal line or the axis of the bubble tube is horizontal.

42. The telescope and its component parts. The telescope may be considered to consist of three essentials apart from the casing or tube,

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*Modern practice is to machine grind the longitudinal tube truly circular at any cross section and the bubble can be rocked through some degrees of arc without disturbing its position.

(1) the object lens with its focussing tube and screw, (2) the eyepiece consisting of single or double lenses and (3) the diaphragm or reticule.

(a) The object lens is a double lens since a single lens would not bring rays to a focus and the image would be fringed with colours, that is, a single lens makes rays planatic and chromatic and so that the rays will be aplanatic and achromatic two lenses are used and they are of the double convex and plano-concave type, the outer one being double convex of crown glass and the inner one being plano-concave of flint glass. The refractive indices of these two kinds of glass supplement each other and the rays are brought to a focus and are colourless.

(b) The eyepiece, when a simple one, has two lenses and the image as seen will be a magnified and an inverted one. The erecting eyepiece or one used to reinvert the image consists of four lenses and if these are named in order from the eye they are as follows :—eye, field, amplifying and image. The erecting eyepiece although it enables the observer to see the image right way up, so to speak causes a loss of light which does not counterbalance the doubtful advantage of reinverting the image.

(c) The diaphragm or reticule consists of cross wires, as they are usually called, made of silk or cobweb stretched across a ring but in latter day instruments the wires are engraved on glass. This ring can be moved horizontally or vertically by means of the diaphragm capstan headed screws and the entire ring of the diaphragm can be removed and replaced after cleaning. In the most modern type of instruments there is no method of adjusting the diaphragm and its position is fixed by the makers.

43. Functions of the components.—The function of the object glass is to focus the object on to the diaphragm and that of the eyepiece is to magnify the image as projected on the diaphragm. The focus of one affects the focus of the other and if the plane of the image does not coincide with the plane of the cross-wires, an apparent movement which is called **parallax** is said to exist. Some modern theodolites and levels are fitted with an extra lens between the object glass and eyepiece which is used for focussing when the object lens is a fixture. This is known as *internal focussing* and its chief merit is that the telescope is sealed with little or no error in the focussing slide and the stadia constant is negligible

except for a distance of less than 15 feet where under ordinary circumstances a measuring tape would be used.

If the component part of lenses of the object glass or eyepiece do not coincide at their axes and if the grinding and polishing is not of the best workmanship there is then a loss in definition. The amount of light passing through the lenses to the eye compared with the amount of light passing from the object to the eye is what is called the lumination of a telescope. The larger the object glass the greater the pencil of rays passing through, but the edges of lenses cannot easily be ground to perfection and as there is really only an effective diameter in the lenses of the cheaper class of instruments, stops are used in the telescope tube to cut off rays from the edges. Under the best arrangements there is a loss of at least 15 per cent. of light.

44. The power of magnification of a lens.—The magnifying power of transits are about 20 diameters and those telescopes made specially for stadia work between 20 and 35 diameters. To find out the magnification of a telescope focus it on some distant object and at the same time see that the lines on the diaphragm are distinct. Hold a sheet of white paper in front of the object glass and look into the eyepiece from a distance of a foot to six inches and a white disc of light will be seen. This disc is the image of the object glass formed by the eyepiece and is known as the Ramsden disc. Measure the diameter of this disc minutely and divide the clear diameter of the object glass by this amount. The result will be the magnifying power of the telescope.

45. The angle of the field of view.—The size of the field of view is the whole circular area which can be seen through the telescope. To determine the field of view set up the instrument at about twenty-five feet from a strip of white paper. Focus on to the paper and get some one to stand by and make two lines on the paper to show where the extremities of the horizontal diameter of the field of view come on the paper. The person at the telescope will direct the one at the strip as to where the marks should be made. Now by means of a theodolite measure the angle subtended by the two marks at the point at which the telescope was set up. This angle represents the field of view.

46. Description of the Transit Theodolite.—The theodolite is the most important instrument used by the surveyor and measures both horizontal and vertical angles.

The transit theodolite may be considered to consist of four main parts as follows :—

(1) The lower frame with socket head and three* footscrews F F F (*see* fig. 24) also C_1 lower plate clamp and T_1 lower plate tangent or slow motion screw.

(2) The lower plate or limbs with primary circle with its outer spindle which fits into the socket of lower frame.

(3) The middle part or upper plate with standards and verniers with spindle fitting into the lower plate. C_2 clamp for upper plate, T_2 tangent or slow motion screw for upper plate, B S bubble tubes (or levels) with adjusting nuts.

(4) The upper works consisting of telescope with fittings, such as the primary scale of the vertical arc, focussing arrangements for lenses, diaphragm etc., also a plate to which is attached verniers. B. N. bubble (vertical arc bubble or level) and stud or antagonistic screws V, (in fig. 24 the antagonistic screw arrangement is a single screw working against a buffer spring). To this arm is fixed the vertical arc clamp screw C_3 and slow motion screw T_3.

Note.—The vertical arc bubble is, in diagram, fixed to the plate carrying the verniers, but in some theodolites it is fixed on the telescope and yet others have two bubbles, one on the telescope and one on the vertical arc.

Consider now the movements of the different plates on the axes or spindles. Let C_2 and C_3 be clamped and C_1 unclamped, then parts 2, 3 and 4 as one piece can be revolved horizontally on the outer spindle working in the socket.

Let C_1 and C_3 be clamped and C_2 unclamped then parts 3 and 4 as one piece can be revolved horizontally on the inner spindle working in the outer spindle.

Let C_1 and C_2 be clamped and C_3 unclamped, then the telescope only can rotate in its own vertical axis.

Finally clamp C_1 C_2 and C_3 and turn screw V and it will be noticed that none of the verniers will register any difference of reading and yet

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* The three footscrew pattern instrument is considered in this book as it is the only pattern used in India and has one or two decided advantages over the four screw pattern in that it is more easily handled (one hand on occasions being sufficient) and because there is little or no strain on the axes.

the upper level B. N. and the line of sight through the telescope will be affected and this movement is an important one to notice when the vertical collimation adjustment is taken into consideration.

47. Permanent Adjustments.—For horizontal and vertical collimation also for horizontality of diaphragm and parallelism of the vertical axis of a transit theodolite.

It is advisable in all theodolites where possible to keep the diaphragm or reticule in the optical axis of the telescope so that the line of sight shall pass through the centre of the lenses that is that the bubble on the vertical arc should be adjusted and made parallel to the line of sight and that the diaphragm should remain as placed by the maker. Some theodolites are fitted with two adjusting screws only for the diaphragm, those for the adjustment of horizontal collimation error, so that in such patterns the vertical collimation must be done on the upper level.

[The anthor considers that an adjustable diaphragm is unnecessary and should be a fixture once and for all in the optical axis of the instrument. Only vertical collimation exists as that is a correction between the horizontal wire and the horizon and can be done on the vertical arc bubble. A horizontal angle is the difference of readings between two objects and whether taken both on the right or left face will give the same result. If the same result is not forthcoming the error is due to the horizontality of the trunnion axis which can be remedied by its own adjusting screws P. P. To take one reading on the left face and the next reading on the right face of course is never intended in the theodolite.]

48. Levelment of plates and lower bubble.—(*a*) Place the lower level or bubble over two footscrews and with these two footscrews bring the bubble to the centre: turn the telescope through 90° when the bubble will be at right angles to its first position and bring it to its centre with the third footscrew only. Repeat this *temporary* adjustment till the bubble remains in the centre in these two positions only. With the bubble axis at right angles to two footscrews (in the second position as above) bring the bubble to its centre by the third footscrew only, turn it end for end, that is, revolve the instrument through 180° and any divergence will be double the real error in horizontality, correct half by the third footscrew and half by the capstan headed screw attached to the bubble. Repeat and correct over these two positions till the error has been dispersed. Next place it over the other two footscrews and correct if necessary by these two footscrews only. The level should be now in perfect adjustment.

The reason for *adjusting* by one footscrew only is that the motion is an even one whereas with two footscrews the motion of the hands in turning may be unequal thus lowering one end more than the other.

(*c*) Since the level on the vertical arc is more sensitive, usually ground to 10 secs. to the lower level of 20 secs, it may possibly happen that the small error unnoticed in the lower level is appreciable in the upper and therefore to put the instrument into perfect level adjustment it is preferable to adjust from the greater to the less or from the more sensitive level to the less sensitive one. Therefore after temporary adjustment (*a*) given above, place the upper level over one footscrew that is, the telescope will be found to be pointing in a line over one footscrew and with the antagonistic screw or screws V bring the bubble to the centre of its run. Turn the telescope horizontally through 180° when the bubble will occupy an end for end position over the same footscrew. Any divergence is twice the error and half is corrected by the antagonistic screw and half by the footscrew. Repeat in these two positions till corrected. Next place the bubble parallel to the other two footscrews and any divergence correct by these two footscrews only since any bubble error has been already corrected. The bubble should now remain in the centre of its run in any position of the upper plate. The reader will realise that if the lower plate levels are not now correct that the error exists in the axis of the bubbles and not in the axis of the instrument; any divergence correct by the capstan headed screws attached to the bubbles.

The above has been given at some length since it is often not understood, why, in triangulation and ordinary star observations for time and azimuth the upper level refuses to keep a medial position, and an instrument undergoing a test for vertical collimation adjustment, and with which many observations for vertical angles are to be made as in some classes of work must be put through the adjustment for bubble axes *vide* (*c*).* An instrument used for traversing need only be put through adjustment (*b*) and ordinarily through (*a*) as a small error in horizontality will make no appreciable difference in horizontal angles. Finally, in connection with the above the reader will see later that observations on two faces eliminate collimation error and that any divergence of the vertical arc bubble on each face can be recorded and allowed for (*see* appendix Part II).

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* It will be seen hereafter that in case of an axial error in a footscrew this adjustment should not be rectified during observational work.

In the plate at screw V there is a second screw just visible and this lock-screw is intended to facilitate the operation of the levelment of the vertical arc at each set up as it regulates the distance of the threads on the antagonistic screw from the bush spring, so that when the lower plates are levelled, the vertical arc bubble should return to its medial position when the spring is released.

49. Horizontal collimation.—In a previous para. it has been asserted that there is actually no horizontal collimation error since horizontal readings on one face are taken from one object to another and provided the graduated arc is free from error or nearly so there is no need to change face. But the instrument may have a trunnion axis error due to the telescope axis not being at right angles to the axis of the instrument so that when high and low objects are taken an appreciable difference is discovered. The adjustment is given in a future paragraph under parallelism of vertical axis but for those who wish to test or require the diaphragm lines to be accurately set in the centre of the field of view and optical axis the following should be carried out:—Clamp the lower plate by C_1 and with the upper plate intersect some defined object such as a rod or finial by clamping C_2 and using the slow motion screw T_2. Let the instrument be on face *left* that is, with the vertical arc to the left as the observer is looking through the telescope. Read the horizontal verniers and let the mean be 120° 16′. Unclamp C_2 rotate telescope vertically and point it again at the object when the instrument will be on face *right*. Clamp C_2 and intersect object by T_2 and let the mean reading be 300° 20′. There is thus a horizontal collimation error of 4′ which must be dispersed. Set the verniers to the mean reading that is to 300° 18′ on face right and the wires will no longer be on the object; bring the wires on to the object by the screws attached to the diaphragm by loosening one first before tightening the other. Change face again and check result. It is not possible to have no collimation error since the graduation of the plates if unequal will upset it and there is also no need for absolute dispersal of error if observations are made on both faces; in fact many surveyors prefer a small collimation error as it prevents them being biased in their readings.

50. Vertical collimation—With a level staff (*a*) when the bubble is fixed on the telescope (*b*) when it is attached to the vertical arc.

(*a*) In the case of the bubble being attached to the telescope set the verniers to 0° 0′ and examine bubble which should be in the centre if the first adjustment has been properly done.

With the instrument on face *left* (the bubble will be on top of the telescope) read to a staff and let the reading be 4·56. Change face when the bubble level will be underneath the telescope and it must be taken for granted that when the verniers are set to 0° 0′ that the bubble will be in the centre. Again read the staff and let the reading be 4·60. Change face again, that is, bring the instrument back to face *left*, set the verniers to 0° when the bubble is again in the centre and *either* move the diaphragm so that the horizontal wire reads the mean *viz.*, 4·58 *or* with the stud screws V make the wire read 4·58 and since the stud or antagonistic screws have been touched the bubble will no longer be in the centre, therefore, bring it back with its own bubble nuts B. N. The latter method is preferable since by altering the diaphragm once for horizontal and then again for vertical collimation there is a possibility of one vitiating the other.

(*b*) When the bubble is attached to the vernier arc the same procedure is carried out with this advantage that on the *right* face the bubble being on the vertical arc it does not become inverted and can be checked for medial position.

51. Another method for Vertical collimation.—By observing two natural objects, with both types of instruments. Select any defined distant object about 5° above the horizon and on face *left* intersect the object and let its mean vertical reading be 8° 52′. Next change face and on face *right* reintersect object and let its mean vertical reading be 8° 50′ checking the bubble on both faces.

There is thus a vertical collimation error of 2′ and the mean reading will be 8° 51′. Return the instrument to face *left* and set the verniers to the mean reading 8° 51′ and as the object will not be now on the horizontal wire manipulate the diaphragm till the wire intersects *or* by means of the antagonistic screws intersect the object and when the bubble level is attached to the vertical arc correct it by means of its adjusting screws BN and when the bubble is attached to the telescope make the verniers first read 0° 0′ and then correct it.

52. Horizontality of diaphragm.—This adjustment should really be made before collimation is taken in hand and though it is not often necessary yet it should be checked. Owing to the diaphragm screws working in slightly larger holes or slots for the purpose of rotating the

diaphragm in its own axis a very small quantity, it is possible by loosening the 4 screws that the diaphragm leaves its true position with respect to the horizontal and vertical wire, that is, it takes on a slight "slew." When the diaphragm has been entirely removed for rewiring of course it is most necessary that the following test is made. First perform the adjustment for levelment and turn the telescope to some mark on a wall or tree or even a level staff and clamp the vertical arc and with either horizontal slow motion screw rotate the instrument from one extreme field of view to the other ; if the horizontal wire does not cut the mark throughout its entire travel then it requires adjusting and this is done by slightly tapping up or down one of the horizontal diaphragm screws after loosening them. The student should notice that without this test he must confine himself entirely, in intersecting objects, to the intersection of the cross wires.

53. Parallelism of the vertical axis.—This adjustment is not always possible with the smaller class of instruments as the necessary screws are not fitted (*see* PP in plate). The adjustment is made on the standards for the transverse axis of the telescope so that the telescope will transit on a perfectly plumb line. Direct the telescope, after the adjustment for plate levels has been made, to a point on a clearly defined object at a considerable elevation, and by means of either tangent screw T_1 or T_2 bring the intersection of the diaphragm wires exactly to bear on that point ; then depress the telescope without touching either tangent screws to a point as far below the first as possible and note exactly the spot at the intersection of the cross-wires. Turn the instrument 180° transit the telescope, that is, change face and again intersect the higher point and depress telescope and if the cross-wires intersect the lower point the transit axis is horizontal ; but if the lower point is not intersected by the cross-wires, correct half the apparent error, that is quarter of the total divergence, by the capstan screw P and quarter of the error by slow motion screw and direct the telescope again to the higher point and note the new position when depressing the telescope. If there is still an error when the instrument is again turned 180° the above operation must be repeated. In the more refined instruments a *striding level* is fitted in the box to test the horizontality of the transverse axis.

It is taken for granted that in the adjustment for collimation, etc., or whenever an object is intersected that the temporary adjustments for focus and parallax have been made. Here a word might be said concerning

modern manufacture. Verniers on the lower plate are set at an angle of $22\frac{1}{2}°$ with a glass cover plate. The verniers are adjustable by means of slotted screws and if dirt happens to get between the vernier and circle it works through without doing any harm. Diaphragm lines can be ruled to an accuracy of $\frac{1}{10000}$ and the thickness of the line is less than half this. The total graduation error in a well-made standard theodolite is about 5 secs. and the thickness of the lines on the vernier or plate is about 0·0015 in. thick. Such lines are easily read by means of readers with a power of 7. Great improvements have been made in the quality and grinding of lenses, setting of footscrews in the trivet head and in the stand of the instrument.

54. The Method of observing with the Theodolite.—The surveyor having satisfied himself that the theodolite is in adjustment can now begin his observations. The adjustments just described are not necessary every time the instrument is set up but only now and then when the surveyor may have reason to think the instrument has been shaken by some means. It is well, however, before beginning a day's work, to see if the adjustment of the levels is correct or not, as it is soon looked to, and will often save a great deal of vexatious repetition.

55. Temporary adjustments to level the Instrument.—This operation is necessary every time the instrument is moved to a fresh position, and is performed in the following manner :—The instrument being placed more or less over the station mark it is approximately levelled up by means of the legs of the stand. It is next carefully centred over the mark by means of the plumbob and then the true levelment must be completed by the footscrews, (FF *see* plate) :—that is that the *temporary* adjustment for levelment must be made by placing the lower level over two footscrews bringing the bubble to the centre by turning the two footscrews evenly either both inwards or both outwards. The left hand is usually the master hand with footscrews, and the direction in which the bubble will travel will be the direction of turn given by the left hand. Next bring the bubble over the third footscrew and repeat till perfect. If the permanent adjustment previously explained in para. 48 has been properly done then two, or at most three repeats, should be sufficient for all purposes of traversing when the vertical arc is rarely used but if the instrument is being used for triangulation then the upper level being the more sensitive should be adjusted first when the lower level will agree if the permanent adjustments have been properly made. Some old and worn instruments often

refuse to remain level in every position of the telescope and time should not be wasted in trying to make such instruments do so and yet for certain classes of work they will give excellent results.

56. Focussing and removing Parallax.—To intersect any object, first obtain a clear image of it by the focus screw at the side of the telescope. Then move out the eyepiece until the cross wires can be seen distinctly. To do this, hold the *socket* of the eyepiece firmly with one hand, and move the eyepiece with a gentle screwing motion with the other. Do not pull the whole instrument by the eyepiece by using one hand only, as it is often stiff. Then by means of the focussing screw move the object-glass (slightly) until the object is clearly seen, and on moving the eye about, the image of the objects will cease to move off the intersection of the wires or to have no fluttering and undefined appearance. The explanation of this is as follows :—a picture of the field of view is formed in the telescope, and until it coincides with the plane of the wires this motion will take place ; just as looking out of a window, the position of the bars with respect to the landscape changes according as we change our position ; but if the landscape was painted on the glass (*i.e.* was in the same plane as the bars) this would not be the case. By moving the object-glass in and out, or as it is called "focussing," the image is brought on to the plane of the cross-wires and if the wires become slightly indistinct or move over the object the eyepiece must be readjusted and so on, that is parallax must be dispersed so that no movement of the wires on the object is visible. The dispersal of parallax is most important.

57. To observe an angle.—By means of the clamp C_2 and its tangent screw (*see* Fig. 24) set the vernier, marked A on upper plate, to 360° on lower plate, then turn the lower limb round, and with the lower clamp C_1 and tangent-screw. T_1 fix the cross-wires in the telescope on any object. Then loosen the upper clamp C_2 and turn the upper limb round, fixing the cross wires by the same clamp and tangent-screw on any other object ; the angle subtended can be then read off on the instrument.

It is not necessary to set the plates together at zero, but clamp the lower horizontal limb firmly in any position, and direct the telescope to one of the objects to be observed by turning the upper plate, moving it till the cross-wires and object coincide ; then clamp the upper limb and by its tangent-screw make the intersection of the wires nicely bisect the object ; now read off the two verniers, the degrees, minutes and seconds

of vernier A, and the minutes and seconds only of vernier B, and take the mean of the readings, thus :—

$$\begin{aligned} A &= 142^\circ\ 36'\ 30'' \\ B &= 142^\circ\ 37'\ 00'' \\ \text{Mean} &= 142^\circ\ 36'\ 45'' \end{aligned}$$

Next release the upper plate, and move it round until the telescope is directed to the second object (whose angular distance from the first is required), and clamping it make the cross-wires bisect this object, as was done by the first, again read the two verniers, and the difference between their mean and the mean of the first readings, will be the angle required.

It is contended by some surveyors that it is best to work with the zero line of the lower plate pointing North and South, so that all readings to any objects are their magnetic bearings. Thus the two plates being clamped together at zero as in first method, the lower plate is set to coincide with the magnetic compass and clamped. The method of observing after this is as in the second method. The only difference being that instead of "any position" the lower plate is set to the Magnetic Meridian.

58. To repeat an angle.—Having taken an angle between two objects leave the upper plate clamped to the lower, and release the clamp of the latter ; now turn the lower plate, *i.e.* both together round towards the first object, till the cross-wires are in contact with it ; then clamp the lower plate and make the bisection with the lower tangent-screw. Leaving it thus, release the upper plate, and turn the telescope towards the second object, and again bisect it by the clamp and slow motion of the upper plate.

This will complete one repetition, and if read off, the difference between this and the first reading will be double the real angle. It is however best to repeat an angle four or five times ; then the difference between the first and last readings (which is all that it is necessary to note), *plus* 360° for each full revolution divided by the number of repetitions, will be the angle required.

59. How to change face.—The face of a theodolite is the vertical arc, and, according as the vertical arc is on the left or right of the observer when he is looking through the telescope, so the instrument is said to have **left** or **right** face. In changing face, the diaphragm is inverted or turned through 180° and the horizontal arc is also turned half round or through 180°.

When the theodolite is a "transit" and its telescope can be completely revolved in the vertical plane, changing face is to so revolve it end for end or through 180° and then to turn the horizontal arc through 180°. It will now have changed face and will be pointing as before.

(Caution in setting up a theodolite—always note that A horizontal arc vernier, is or should be, the vernier directly beneath the vertical arc.)

With the double arc Everest the process is a little more complicated, because the telescope cannot be completely revolved in the vertical plane. It has to be taken out of its Y's and the following three half turns have to be made :—

(1) The vertical arc verniers are made to change places.

(2) The pivots or trunnions, which rest in the Y's are made to change places.

(3) The diaphragm is inverted and when the telescope is put back in the Y's two essential points must be secured, *viz.* telescope should point as before, and (2) each trunnion should sit in the proper Y.

Hence the following *modus operandi* :—

(1) Remove the compass and sometimes also the clamping screw of the vertical arc.

(2) Loosen the stud or antagonistic screw and open the Y's.

(3) Unclamp the vertical arc if not already unclamped and lift the telescope out of its Y's taking care to keep it *always* horizontal with its object-glass pointing to the object. This should be done without jar or shake.

60. The magnetic compass for attachment to a theodolite is of the rectangular trough pattern. The needle is magnetised and weighted to overcome the dip and rests on a pivot which works on an agate. The compass should not be used when the instrument is not level and the needle should always be thrown off its pivot when not required. In some Continental instruments means are provided for adjusting the compass so that it will show true bearings and not magnetic bearings. The magnetic bearing of an object is taken by simply reading the angle pointed out by the compass-needle, when the object is bisected : but it may be obtained a little more accurately by moving the upper plate (the lower one being clamped) till the needle reads zero, at the same time reading off the horizontal limb ; then turn the upper plate round to bisect the object and

read again ; the difference between this reading and the former will be the bearing required

61. Angles of elevation and depression—In taking angles of elevation or depression, it is scarcely necessary to add, that the object must be bisected by the horizontal wire, and in preference at or near the intersection of the wires, and that after observing the angle with the telescope in its natural position it should be repeated with the "face reversed," *i.e.*, with the horizontal axis reversed end for end in its bearings : the means of the two measures will neutralize the effect of any error that may exist in the line of collimation provided that the bubble is in the centre on both faces.

The altitude and azimuth of a celestial object may likewise be observed with the theodolite, the former being merely the elevation of the object taken upon the vertical arc, and the latter its horizontal angular distance from the meridian.

62. How to level with a theodolite.—Place the instrument *medially* between the stations whose difference of level is required. Perform the temporary adjustments. Tighten the stud screws and clamp the vertical arc in some convenient position not necessarily horizontal. Read the levelling staff placed on the pegs successively by unclamping the lower plate. The difference of the readings will give the true difference of level notwithstanding instrumental errors. The upper level is not used at all. The arm carrying the verniers does not revolve. Hence if the instrument is in adjustment as regards the virtual line of sight, the line joining the zeros of the vertical verniers will be horizontal when the upper bubble is at the centre of its run (*see* adjustments paras. 50 and 51) but the zero will seldom coincide and as shown above it is not really necessary that they should.

63. Definitions of the terms Right and Left swing and setting.—A swing is a continuous rotation of the telescope horizontally beginning and ending with a zero. Several angles may be observed in the case of a *swing*. It is clockwise or counter-clockwise, commonly known as right or left swing.

A setting is the exact division on the limb or arc to which A vernier is clamped at the commencement of a round of observations. The "zero" includes a pair of settings on different-faces, right and left, and may be 0°

and 180°, 60° and 240°, 90° and 270° etc. If the first zero is 0° and 4 zeros are to be observed on, then the next zero is found as follows :—
$\frac{360^\circ}{\text{No. of verniers} \times \text{No. of zeros}}$ Thus with two verniers and 4 zeros the next zero will be 45° and the 4 zeros will be 0°, 45°, 90° and 135° ; with 3 verniers and 8 zeros the next zero will be 15° etc., with 2 verniers and 2 zeros the zeros will be 0° and 90° and 0° and 90° are sufficiently accurate with modern theodolites for Engineering purposes.

64. Errors in using a theodolite.—There are many errors and a surveyor must have a fairly competent knowledge of their varieties before he can get an intelligent grasp of the means employed, as far as is possible to eliminate them. Errors might be conveniently placed under the following heads (*a*) Error of manufacture and errors in the instrument through non-adjustment and usage : (*b*) Errors of observation : (*c*) Local errors : (*d*) Errors of record. Errors therefore are best treated under two heads, *viz*, errors of instrument and the general sources of errors when using the instrument, and are as follows :—

(1) Diaphragm wires not vertical and horizontal and adjustments for levelment and collimation.
(2) Shake in the footscrews and stand and settling of the stand or tripod.
(3) Errors of parallax and of the focussing slide.
(4) Eccentricity of circle.
(5) Errors of graduation and drag on verniers.
(6) Worn threads of slow motion screws.
(7) Bad centering of instrument.
(8) Bad centering of object observed to.
(9) Poor focussing.
(10) Undue pressure in clamping.
(11) Vibration under strong winds and temperature changes, causing unequal refraction.
(12) Using the wrong tangent screw for horizontal angles.
(13) Placing the hand on the stand when observing.
(14) Using an instrument which has become clogged with oil and dirt or has been previously damaged.
(15) Swinging the upper plate around by the telescope instead of by the standards.
(16) Bad intersections of object and incorrect reading and recording of values.

(17) Manipulating footscrews for levelment between a set of horizontal readings.

65. Precautions.—To treat with them in detail, errors under head :—

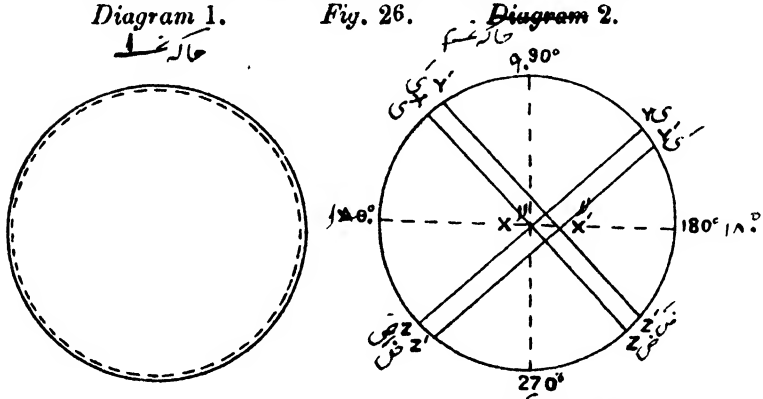
(1) Have been explained under adjustments (*see* transit theodolite adjustments) but it must be borne in mind that it is loss of time to try and dispose of collimation errors absolutely.

(2) The stand when set up should have its clamp nuts thoroughly tightened and the tripod should be well and firmly set into the ground. There should be no possible shake.

(3) Parallax should be properly dispersed and the focussing slide should be examined to see, when it is moved in and out, that an object is stationary on the wire and does not appear to wobble as it comes into and goes out of focus, from one side to the other. There may be an error in fitting of the tube and grinding of the lenses. Such errors of slide and lenses are best corrected by an instrument maker. The ratchet and wheel of the focussing arrangement should be treated occasionally with a dressing of beeswax.

(4) *Eccentricity of circle.*—This is due to the axis of the horizontal vernier or of the upper plate and the axis of the limbs not coinciding and the result is that although the zeros of the verniers may be exactly 180° apart and the graduation of the instrument perfect, there is a variable difference of reading over different portions of the plate. The error in the zeros of the verniers would give a constant difference and the mean reading of the two would disperse the error.

Diagram 1. *Fig.* 26. *Diagram* 2.



The error in eccentricity is usually so small that it can be neglected, but the diagrams will show how an error is introduced which is variable and not a constant.

Diagram I Fig. 34 shows no eccentricity as the centres are coincident.

Diagram II Fig 34 shows eccentricity as X is the centre of the limb and X′ the centre of the vernier or upper plate axis.

Let the two centres be in a line with the 0° and 180° of the limbs. Then the following conditions will arise:—

At 0° and 180° there will be no error.

At 90° and 270° there will be a maximum error.

Between 0° and 180° the vernier Y′ will read too much.

Between 180° and 360° the vernier Z′ will read too little.

Error dispersed by using several zeros.

(5) *Errors of graduation.*—In most modern instruments the errors of graduation are reduced to a minimum, but what errors exist can be dispersed by observing on different parts of the limb for each station or what is technically known as a different setting of zero. The error of drag or the slight adhesion or friction of the vernier on the limb which causes it to be held back is neutralised by observing stations on a forward and also backward swing (left and right swing).

(6) Worn threads on the slow motion screws specially when such screws are acting against a spring, cause a slip of the plate and this may happen between the intersection of the object on the wire and the reading so that the reading may be as much as 10 minutes incorrect.

The screws should be rethreaded or if this is not possible at the time, the screw must be used on a good portion of the thread and the intersection should be again examined after the reading has been recorded.

(7) and (8) Great exactness in centering of instrument is necessary and specially in mining and tunnelling work where meridians above ground have to be transferred down a shaft, and a personal interest in it should be taken so as to convey to other members of the party at work what is expected of them when they are sent out on independent work to set up signal flags and helios.

(9) On triangulation poor focussing means that the focus is not at infinity, as it should be for more or less distant signals and if there is any error in the slide and draw tube altering the focus must bring in the slide error if any exists.

(10) Clamps should be tightened with just sufficient pressure to make them hold which is usually very little indeed. Any undue pressure might lead to one part of the vernier plate being strained and to a slight jump when the tension is relaxed. A delicacy of touch in handling instruments is a sure way of obtaining good results.

(11) Observations taken under adverse atmospheric conditions should be avoided if possible. A good intersection is impossible when the air is "boiling." Refraction is greatest in the early morning and late evening and least between the hours of 11 a.m. and 3 p.m. and 1 p.m. is the best time to take vertical angles on triangulation.

(12), (13), (15) and (16) are either mistakes or bad habits.

(14) and (17). The instrument should be first tested for adjustments and if it fails to come up to the standard of accuracy required for the particular work in hand it should be returned for epairs. The part most liable to injury is a footscrew and in a good instrument when the telescope rests over a footscrew and on that screw being turned the line of sight should move up and down vertically; if it moves also to one side or "rolls" it is in poor order but still will give good results so long as after the levelment of the bubbles the footscrews remain *untouched* throughout the observations taken for horizontal angles. This is important to remember.

66. Useful hints on the use of the Theodolite.—A few hints on the use of these delicate instruments are here added.

1st. They must not be handled roughly. In taking them in and out of the box, it should be done with the greatest care, not knocking them against the sides of the box or forcing them into their positions within it; the boxes are so constructed, that the instrument fits exactly into its own place, and unless it settles down of itself, forcing it will throw the instrument out of adjustment. If not already done, the sides of the box should be marked to show the proper positions of the ends of the telescope, and the lower plate clamping screw, and perhaps the position of the verniers as they turn independent of either plate. This allows of the instrument being arranged outside the box and put in at once. After placing the instrument in the box all clamps should be tightened, and springs, such as those attached to micrometer screws released.

2nd. In using the instrument it should always be handled by its substantial parts, not twisted round by the eyepiece, as careless surveyors constantly do; and before attempting to turn any part, care should be taken to see that the clamp is loose and it is free to turn. A little attention to do the proper thing at first makes it a habit and just as easy as the wrong one.

3rd. Always throw the magnetic needle off its centre by the stop fixed on one side of the box when the instrument is not in use, as the constant playing of the needle wears the pivot upon which it is balanced, and on the fineness of this point depends the accuracy of the bearing. This is equally applicable to the Prismatic Compass.

4th. It may not be superfluous to remind surveyors that although instruments are adapted for use in the field, the less their various axes, screws, etc., are worked the longer they are likely to last in an efficient state. The setting-up and adjustment should, therefore, be effected with the least possible amount of motion and if the instrument is to be carried without being replaced in its box the clamps must be tightened to prevent their axes swinging and taking up unequal wear.

Micrometer screws should require but a touch after the clamps have been tightened, and the levelling of the instrument should be done as nearly as may be by moving the legs before using the footscrews.

5th. If any part of an instrument be found to work stiffly, the cause should be ascertained before proceeding further, and removed. A single grain of sand getting in between a pivot or axis and its socket will often jam them firmly together, besides making a spiral score round them, not easily effaced. Want of oil invariably causes wearing in those parts subject to constant friction. Good neatsfoot and salad oil are best lubricators, and in their absence "til," well clarified by simmering over a slow fire, and straining through fine flannel (the process to be repeated until the oil is colourless, or nearly so). Clock oil is obtainable in most bazars and is the best. It should be applied in the *smallest possible* quantity, and *only to the parts exposed to friction.* None on any account to be applied to the *footscrews*, or micrometer screws. Any oozing out at joints or shoulders should be carefully wiped off. Every part of an instrument exposed to the air should be kept perfectly dry; and before commencing work, should be carefully freed from dust by a camel hair brush *not* with a cloth.

6th. Always keep the instrument as clean as possible, see that there is a good outer padded cover, and fill the inside of the box and the top with loose cotton wool wrapped in paper so that the instrument will again be protected. Have stout straps fixed on to the boxes to carry them by and always have them carried by men, not in carts. Wipe all dust off carefully both on commencing and leaving off work. The instrument will repay your care, and it keeps you in good temper to have it working easily. On the care a surveyor takes of his theodolite, depends much of the accuracy of his work; if he neglect and be careless about the former, he will one day have to lament over the accumulated errors of the latter.

Instruments not in use and not expected to be in use for some considerable time should have the lid opening and any cracks in the woodwork of the box pasted over with slips of paper to prevent dust lodging on the instrument. Where dust storms are prevalent this is a very necessary precaution to take.

7th. Object-glasses often become clouded: and if the cloudiness is not removed by cleaning both faces of the lens the glasses of which it is composed should be separated, and the inner surfaces carefully cleaned; if this be not done, the cloudiness will probably become permanent, and can only be removed by repolishing by the instrument maker. Soft wash leather, or ether and a brush carefully freed from grit or dust, will be found the best material for cleaning either the glasses or finer portions of the metal work. If the leather or a silk handkerchief be moistened with spirits of wine or liquor ammonia, the rubbing will be more effectual in removing cloudiness from glasses. Lenses when taken to pieces must be carefully replaced as found and the whole glass must be screwed back into the telescope as left by the maker. Some makers cut marks, one on the ring holding the glasses and one on the telescope rim, showing when the position is correct that is when the lens is "square."

8th. The cross wires, when not of platinum or floss silk, are best made of cobweb; the finest and cleanest are those found on bushes and long grass; they can be attached to the diaphragm with Canada balsam, common lac dissolved in spirits, or any gum moistened with *diluted* spirits, or, in default of any of the above, with a little beeswax. The gum should be put lightly on the diaphragm, and the thread taken between the points of a pair of compasses gummed also to make it stick, and opened wider than the diaphragm. The thread can then be carefully laid on. Thin glasses with lines scored on them are now made. These are practically

indestructible, but if made of inferior glass are liable to become obscured by a branching sea-weed like fungus, for which the only remedy is to get a new diaphragm-glass.

9th. The variation of the compass needle from the meridian in every instrument should be ascertained, either by actual observation according to any of the usual methods, or by comparison with some other instrument of which the variation is known; and recorded with the name of the place where it was observed on a paper pasted on the inside of the instrument box or case. Date also to be noted.

10th. To take an instrument to pieces for cleaning purposes it is necessary to unscrew all clamps and tangent screws, next to unscrew the lower axis spindle screw. The plates will generally be found to come apart in three pieces. For ordinary cleaning there is usually no necessity to go further, but if the vertical arc axis requires looking to, the small screws keeping the plates together will have to be taken out and they must be returned to their correct positions. Some makers dot screws and holes so this may be done. Any old oil and dirt should be cleaned off with kerosine and then the clock oil used and wiped off. Too much oil is as bad as none at all and the slightest smear is sufficient. The graduated arc and verniers can be washed and cleaned with soap and wash leather and the engraving filled in by camphor black and oil rubbed in by the finger passed lightly over the silvered portion and allowed to dry and 24 hours afterwards gently wiped off. The edges of the verniers are sharp nd soft and are easily burred if carelessly handled. Dust is always a greater enemy than damp. Except when cleaning the graduated limbs and verniers, when they need it, perhaps after a few years work, they should *never* be touched by the hand.

67. Choice of an instrument.—Since there is something to be said as to the choice of a theodolite it would be advisable to add that a standardised instrument is cheapest in every way and the author of this work has, under the orders of Government, designed such an instrument embodying every possible improvement in design at a minimum cost.

68 India Office Pattern Theodolite.—The following are some o the features of the latest-designed standard India Pattern Theodolite (*See* Figure 26.)

elescope.—Tubes of Duralumin, enlarged end with ray shade, internal focussing, transitting both eye and object end. Focussing screw in the trunnion axis of the telescope. Object glass 1·5 inches clear aperture

with a focal length of 9·5 inches, eyepieces screw focussing with dark glasses. Diaphragm mounted on parallel glass engraved with stadia lines $\frac{1}{100}$. Can be removed for cleaning but otherwise sits in its mount and is fixed in the optical axis of the telescope.

Footscrews to be fitted into the tribach at $2\frac{1}{2}$ inches distance apart and each footscrew to have the split screw and taper cone method of taking up periodical wear.

Horizontal limbs to have a reading edge inclined at $22\frac{1}{2}^{\circ}$ to the axis and with a diameter of $4\frac{3}{4}$ to 5 inches and to be fitted with tangent and slow motion screw with different milling of heads. Both slow motion screws to be carried on the same bracket is preferred.

Vernier plate.—The verniers to have a bevelled edge with glass plates fitted to the openings which can readily be cleaned. Clamp and tangent screw as above. Scales to be of silver the "left" face vernier to be marked A, the other B. The verniers to have readers of the hinged Ramsden type and screw focussing. Edge of vernier to be in the centre of the field of reader.

Dividing.—The horizontal limbs to be divided to 20 minutes and figured every 10 degrees. Verniers to be divided to read to 20 seconds and to have two extra divisions at either end of vernier scale.

Standards.—The uprights to be A frame pattern and preferably cast in one piece with the upper plate. Change of pivot possible though adjustment of trunnion axis be a maker's adjustment.

Vertical Limb to have a silver scale, the circle to be rigidly attached to the telescope. Vernier arms to be in one casting with screw focussing readers. Clamping arm to be on the transit axis remote from the circle and to have a die clamp and slow motion screw. Dividing as above and from 0° to 90° each way. Object glass end vernier to be marked C, the other D.

Compass.—Trough pattern to fit on the right standard left face.

Bubbles.—One to be mounted on vernier plate value 40″ and the principal bubble on the bubble stage of the vertical circle value 20″ both to be adjustable. Tubes to be of regular curvature and filled with a mixture having a low surface tension suitable for India. All the bubbles and mounts to be interchangeable.

Stand.—Preferably of oval section ash legs fitting into a tripod head which can be controlled by a screw acting against a metal sleeve or other device so that the tension of the ball and socket jointing can be regulated to avoid shake, etc. Shoes of stand to be stirruped,

Centering head to be in the instrument and not on the stand as it can then be protected and is less liable to damage.

Accessories and spare parts to complete the whole such as dark glasses plump bob (to screw in case), extra diaphragm, bubble, etc. Instrument to pack in one box and to have a canvas case with webbing straps.

The above is only a short description but it will suffice to show how the standardised instrument has been thought out and the user will obtain the very latest devices necessary to ensure good results with the minimum amount of fatigue.

69. The Solar Attachment (*fig.* 28) is in favour in America for all public land surveys as a means by which the telescope is set on the meridian, that is true meridian, in preference to a magnetic meridian. To thoroughly understand its principles the reader is requested to study the chapter on Astronomy Part II and when he has done so he will understand that when the solar attachment is placed on the telescope and if he were in latitude 45°N, and the telescope depressed so that the object and vernier reads 45° (colatitude) with the object glass towards the north that the eye end of the telescope will intersect the celestial equator and that the axis of the attachment will be parallel to the axis of the earth at the place (*see* plate). If the vernier of the *attachment* is clamped at 0° then the line of sight passing through the solar lenses would be parallel to the line of sight of the telescope and if the attachment is in adjustment when the sun is at one of his equinoctial points then on the instrument being rotated the sun will be focussed in the small square of the mirror. Now the sun's ~~declination~~ varies every few minutes so that an arc to include his full decliuation N. or S of 23° 27½′ is required and hence the arc and vernier of the attachment. The sun's declination and variation per hour for Greenwich, day by day, is given in the nautical almanac from which the declination for any hour at a place E or W of Greenwich is found. As the apparent sun (true sun) is being observed to, its elevation or altitude on account of refraction will be greater than its true altitude and thus it is necessary a few minutes before making the observation for meridian to roughly obtain his altitude and from the table of refractions and his calculated declination to correct to apparent altitude. At the foot of the attachment is the hour circle divided to 5 minutes of time and by rotating the attachment on its own axis the hour circle can be set to any time at which the observation is to be made. For example, let the standard

time at the place be known. Correct this to local mean time and this again to Greenwich time of observation. In the nautical almanac look up the sun's apparent declination at Greenwich mean noon for the date of observation and correct the declination considering the sun's variation as given between the time of Greenwich mean noon and the Greenwich time of observation. (The variation per hour is given in a separate column in the N. A.) Having obtained the declination correct for refraction set the hour circle to the selected local time and by rotating the whole instrument the sun's image is focussed between the engraved lines on the mirror *when the line of sight through the telescope cannot occupy any other position but on the meridian.* If the sun has a S declination then the attachment will be reversed or occupy an end to end position opposite to that given in plate. The upper plate of the theodolite should be clamped to zero and the lower plate unclamped and the instrument rotated till the sun is focussed when the lower plate is clamped and if the upper plate is now unclamped and a reading taken to an object, the reading will thus represent the bearing or inclination of the object from true north. Observations to be reliable should not be taken within an hour of noon.

There is an improved pattern which is more accurate since it is fitted with a telescope and on transfrontier or reconnaissance work with the meridian fairly accurately found by this attachment an observation from two known stations would be sufficient to fix the point. Tables for refractions and declinations for use with the solar attachment are extant and simplify work considerably.

70. Levels, their designs and adjustments.—Designs in levels* are now practically confined to three types. *The Wye* or Y, *Dumpy* and the *prism or reflecting* pattern level.

71. The Wye or Y level (Fig. 29) is so called because the telescope rests in Y supports and its permanent adjustments are as follows :—

See that the instrument is securely screwed home in its stand and that the tripod is quite firm and rigid ; bring the footscrews F F to the centre of their run and roughly level by means of the legs and press the legs well in to the ground.

Place the telescope over one footscrew and bring the bubble into the centre of its run by this footscrew and clamp the instrument by the clamp C (*see* Fig. 30).

* Rough levelling instruments, such as clinometers, Abney level, De Lisle clinometer, Ceylon Ghat tracer, etc., are not included in this category.

(1) Twist the telescope, after first loosening the clips, to one side and then the other on its vertical axis. If the bubble moves then it shows that the axis of the bubble and the axis of the telescope are not in the same plane. Adjust for lateral motion by the screws fitted for the purpose on the side of the bubble opposite to bubble nuts B.

(2) Reverse the telescope in its Ys. and if the bubble does not come exactly in the centre of its run adjust half the error by the nuts B. and half with the footscrew F.

Repeat the operation till the bubble remains in the centre, whichever way the telescope lays in its Ys.

(3) Revolve the instrument on its axis about 180° and if the bubble is not in the centre of its run adjust half the error by means of the Y, nuts Y. and half with the footscrew : then turn the instrument through 90° so that the telescope lies over the other two footscrews (if a 3 footscrew pattern) and correct any divergence by these two footscrews and repeat this operation till the bubble remains correct in whatever position the instrument is turned on its axis : the clamp screw C. will have been loosened.

(4) Now put in the clips and look through the telescope and see whether the wires of the diaphragm are truly vertical and horizontal that is whether the frame which carries the diaphragm glass or the frame on which wires are fixed has not been twisted. Select any object and gently rotate the instrument on its axis by the slow motion screw T and if the horizontal wire leaves the object then adjust it horizontally by a slight twist in the sleeve through which the diaphragm nuts D. work.

(5) Turn the instrument and clamp it on some well-defined spot, disperse parallax, unclip the Ys. and note the exact spot intersected by the two wires. Revolve the telescope in the Ys. on its own axis half way round and if the object has moved laterally or in a horizontal direction correct half the error by the diaphragm screws D. D. giving lateral motion and half by the slow motion screw T. Revolve the telescope a quarter turn and correct the vertical wire in a similar manner.

Repeat this operation till the point of the intersection of the wires remains stationary when the telescope is revolved. Adjustment 5 can be made first, in fact some levellers prefer to make this their first adjustment.

The following will make the above clear. *See* Figs. 31 and 32.

Adjustment 1 has been explained.

Adjustment 2 is to make the axis of the bubble parallel to the line of sight and axis of collars.

Adjustment 3 for the Y supports, so that the axis of the bubble is parallel to the level bar which is at right angles to the vertical axis of the instrument,

Fig. 31.

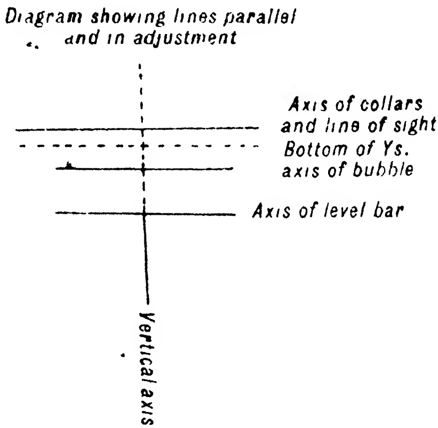
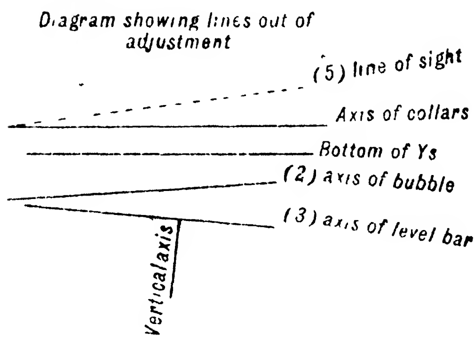


Fig. 32.



Adjustment 4 for the diaphragm ring so that the wires are vertical and horizontal.

Adjustment 5 to make the line of sight pass through the cross wires and the optical centre of the object glass.

Again adjusting from the line of sight down to the vertical axis.

Adjustment 4 having been made for verticality of diaphragm adjustment 5 is made so that the line of collimation is coincident with the axis of revolution of the telescope in its Ys. In other words the line passing through the optical centre of the object glass and the intersection of the cross wires is made parallel to the axis of the collars.

Adjustment 2 is to bring the axis of the bubble parallel to the bottom of the Ys. and in a perfectly made instrument, this means parallel also to the axis of the collars and the line of collimation.

Adjustment 3 as before so that finally the line of sight is made at right angles to the vertical axis of the instrument.

This is known as the direct method of adjusting. (*See* para. 76).

72. The Dumpy level is so called on account of its compact form (Fig. 33).

The permanent adjustments are as follows :—

(1) To make the axis of the bubble at right angles to the vertical axis of the instrument. It is necessary that this adjustment is made before the adjustment for the virtual line of sight.

Place the bubble tube *l* over two footscrews SS and by means of these footscrews bring the bubble to the centre of its run. Next place the bubble tube at right angles to the first position or over the third footscrew (if it is a three screw instrument) or over the other two screws (if it is a four screw instrument) and bring the bubble to the centre of its run. Return to the first position and repeat these two operations till the bubble remain steady in the centre remembering that the telescope has not been turned end for end in the operations. This constitutes a *temporary* adjustment (*see* para. 55). The vertical axis of motion will now be *nearly* vertical and the bubble axis nearly horizontal.

(2) Now place the bubble tube over any footscrew and bring the bubble to the centre by that footscrew and then gently reverse the position of the telescope end for end ; any deviation of the bubble will be twice the real error of perpendicularity. Correct half the deviation by the nuts at the end of the bubble tube by loosening one and tightening the other and half by the footscrew and repeat till perfect. The axis of the bubble has now been made truly horizontal. Place the bubble next over the other two footscrews and correct any divergence by these footscrews only. The axis

of the bubble is now at right angles to the axis of the instrument [compare para. 47].

(3) To make the line of sight parallel to the axis of the bubble and hence at right angles to the axis of the instrument. (Known as the peg adjustment or running a level line in the air).

Set up the instrument exactly midway between two pegs on a fairly level piece of ground so that one footscrew will be directly in the line of the telescope when the telescope is pointing in a direction of the pegs. Bring the bubble to the centre of its run and observe a staff on one peg and record the reading. Next move the staff to the other peg and record the reading and tap down the higher of the two pegs till the staff readings on the two pegs read alike. The two pegs will be on the same level since any instrumental error is cancelled provided the bubble is in the centre of its run when the observations are made and the instrument is midway between staves.

(4) Now take the instrument to a position in the same line as the two pegs either again between the two pegs or beyond one peg so that the distances between the pegs and instrument are unequal, the position beyond one of the pegs is the better one. Bring the bubble to the centre of its run and if the readings on the staff held on one peg and then on the other are not alike then the collimation or line of sight is not correct. To adjust the line *either* adjust the diaphragm by raising or lowering it so that the readings are alike in proportion to the distances, remembering that if the reading on the further staff exceeds that on the nearer it should be moved up and *vice versa; or* lower or raise the telescope by the pair of collimating screws LL* directly under it, till the horizontal wire gives the same readings on the staves when it will be found that the bubble will have left the centre of its run when it must be brought to the centre by the adjustment nuts for the bubble tube (*see* Fig. 33).

The adjustment by the collimating screws which are just under the telescope permits of the diaphragm being left just as the maker placed it and which should be, in preference, in the optical axis of the telescope.

When the telescope is raised or lowered by these screws LL the bubble naturally will no longer be in the centre, but as the footscrews are not touched when the bubble is brought back to the centre, it will then remain

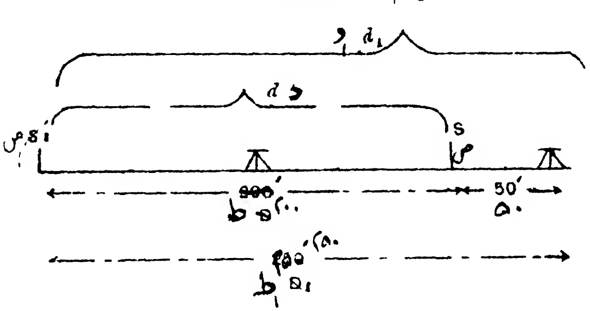
* These collimating screws serve the same purpose as the antagonistic or stud screw in a theodolite.

in the centre in all directions. If an instrument is not fitted with collimating screws then the diaphragm must be raised or lowered.

73. There is no necessity to obtain the same height for the two pegs, for instance let the instrument be placed midway between two pegs S & S_1 such that the distance D between them be 200 feet and the reading on S = 2·81 and the reading on S_1 be 4·66. The difference in height 1·85 is the true difference as the errors if any of the instrument are equal and opposite and therefore cancel.

Now place the instrument 50 feet beyond S so that it will be 250 feet from S_1 and in the line of S & S_1. Let the readings on S & S_1 be 4·80 and 6·83 respectively. Since the new difference is 2·03 it shows that the line of sight is not truly level. By similar triangles the difference on S_1 will be $\frac{D_1}{D}(d_1 - d)$ where d = the difference of the first readings, *viz.*, 1·85 and d_1 = the difference of the second readings *viz.*, 2·03 ∴ difference on $S_1 = \frac{250}{200}(2·03 - 1·85) = ·225$ and therefore the line of sight to be level will read $6·83 - ·225 = 6·605$ on S_1 and as a check $4·80 - \left(\frac{·225}{5}\right) = 4·755$ as the reading on S.

Fig. 34.



74. Another method—Another method and probably the better method is to set up the instrument say close up to peg S so that the staff held on S will nearly touch the eye end of the telescope when the object end points to S_1. Level up the instrument and read the staff on S by looking through the *object* end of the telescope the true *height* of the axis of the telescope or line of sight on S will be the central graduation as seen. Send the staff to S_1 and read it noting that the bubble has remained in the centre of its run.

If the instrument is in adjustment the difference of the staff readings will be the difference of heights of the two pegs ; if the instrument is out of adjustment then the difference of the staff readings plus or minus the error in adjustment will give the true difference in elevation of the two

pegs. The instrument is next set up close to the peg S_1 and under the same conditions as at S the staff is again read. The true line can be calculated on S from S_1 as follows:—

Example.—Instr. at S ; staff reading of S = 4·36.
Ditto do. S_1 = 5·41.
Difference of elevation in S & S_1 = 1·05.
Instr. at S_1 staff reading on S_1 = 4·89.
Ditto do. S = 3·56.
Difference of elevation in S & S_1 = 1·33.

Then $\frac{1 \cdot 05 + 1 \cdot 33}{2} = \frac{2 \cdot 38}{2} = 1 \cdot 19$ true difference in elevation and as it is obvious that the peg at S is higher than the peg at S_1 and as the instrument is fixed at station S with the line of sight at S_1 of the centre of the object glass reading 4 89, then the true line of sight at S_1 on S will be the reading 4·89---1·19 = 3·70 instead of 3 56.

With the diaphragm screws DD (*Fig.* 33) move the horizontal wire to read 3·70 on S and the instrument will be correctly adjusted, or raise or lower one end of the telescope by the pair of screws LL just under the telescope to the computed new reading. This will throw the bubble out ; now adjust the bubble by bringing it back into the centre by its own capstan head screws, the footscrews remaining untouched.

75. **A simple method.**—The two methods just given suggest a combination of both which may be preferred by some surveyors. On setting up the level midway between two pegs and having rid the bubble of any error by the first adjustment (*vide* para. 73) the staff is read say on peg A with a value of 5·68 and it is also read on peg B with a value of 6·68 that is, the difference is 1·00 or B is one foot lower than A. The instrument is now taken to A and set up near the peg so that the staff held on the peg will just miss the eyepiece of the telescope which again should rest over one footscrew. The instrument is levelled and bubble corrected (adjustment 2) etc., and the staff is read at A by looking through the object glass of the telescope. Let us suppose the reading is 4·86 that is that the height of the line of sight is 4·86′ above A and since B is 1·00′ lower than A then the line of sight to be correct or horizontal must strike the staff held on the peg at B at 5·86′ ; if not correct accordingly by diaphragm screws or collimating screws. It appears to the author that of all the methods of adjusting the level by the peg method this is perhaps the quickest and best understood and it is least liable to error as the focus

does not require altering. The adjustment in fact could be tested every morning at the first set up by obtaining the difference of height of the first two pegs and then an extra two minutes' work by setting close up to the second peg. The adjustments by the peg method might be considered *indirect methods*.

76. Comparison between the Wye and Dumpy Levels.—The Wye level is from an optician's point of view more perfect than the Dumpy form as the line of sight must pass through the centre of the lenses or the axis of the telescope and the line of sight are one and the same thing but this assumes that both the Wye supports have been ground not only circular but of exactly the same diameter and that the telescope again bears evenly in the supports. This might be true when the instrument is new but may not be so after long use.

The Wye level can be adjusted by both the direct method (adjustment *vide* para. 71) and the peg adjustment method and Wye levels have been known to be adjusted by the direct method and yet fail under the peg or level line in the air method (indirect method) in which case under these conditions, the latter adjustment should be resorted to, and accepted and the instrument, worked under these conditions, will give excellent results. The Wye level is made up of a good many loose parts and is therefore a more delicate instrument to handle than the modern Dumpy, which is compact and is therefore less liable to get out of adjustment and though it cannot be tested for adjustment by the direct method it is easily adjusted when such adjustment is required by the method recommended in para. 79.

77. Cushing's Reversible Level.—The peculiarity of this instrument is that the object-glass-piece and eyepiece are interchangeable, each being secured to the end of the telescope tube by a slot and pin arrangement only. The express object of this arrangement as stated in paper No. 1659, Vol. LIX., of the proceedings of the Institute of Civil Engineers, is to enable Gravatt's Method of Adjustment to be applied with facility; in other words, to enable the line of collimation to be brought to coincide with the virtual line of sight, which, as has been pointed out in the Appendix, is unnecessary.

The three adjustments are thus described in the paper above referred to:—

1st. *The Vertical Collimation.*—Set up the instrument on its stand, either in or out of doors, with one footscrew under the telescope and without reference to the level of the instrument. Take out the small fixing screw at the top of the object glass cell, and, having

focussed the cross lines, direct the telescope on any convenient object; and bisect it with the horizontal line, ascertaining at the same time that there is no parallax in the telescope. Now carefully turn the eye-end in its socket from right to left, until the holes in the flange of the eye-end are opposite the heads of the screws in the socket, and remove it; then replace it again, but in an inverted position, taking care to turn the eye-end from left to right until it comes to a stop, when the lines will be in their proper position. If the point be still bisected, the collimation is perfect; but if not, correct half the distance of its deviation from the horizontal lines by the footscrew under the telescope, and the other half by the two screws that give vertical motion to the diaphragm carrying the disc with the cross lines. Repeat till perfect

2nd. To make the line of collimation perpendicular to the vertical axis—The object being now bisected, and all parallax eliminated, remove the eye-end and the object glass cell from their respective sockets, and place them in the opposite ends of the telescope. If the object is still bisected, on turning the telescope half round the line of collimation is perpendicular to the vertical axis; but if not, correct half the error by the two large clamping-nuts at one end of the horizontal limb, and the other half by the footscrew under the telescope. As soon as it is found that the eye and object-ends can be reversed without any apparent change of position in the object intersected, the small fixing screw should be returned and the object cell made secure. It is important, in changing the object glass from end to end, to keep that part of the cell which has the small screw holes in it always uppermost.

3rd. To set the bubble tube parallel to the line of collimation.—Level the instrument stand approximately by the legs, and turn the telescope so that it is parallel to two foot screws, bringing the bubble by their motion to the centre of its run. If it remain so, on turning the telescope half round, the level is correct; but if not, bring the bubble half way back by the footscrews over which it stands and the other half by the two opposing nuts at the eye-end of the bubble-tube. Having perfected this, the levelling must be completed by turning the telescope a quarter round, so that one end of the level is over the third footscrew, by which the bubble must be brought to the centre of its run. The bubble should now remain in the centre during a complete revolution, and the small cross level can then be adjusted."

It is claimed for this arrangement that "the facility of adjustment of the Y level is preserved," together with the "greater stability of adjustment of the Dumpy."

78. Lines common to all levels.—To summarise, levels may be said to contain three important lines (*a*) the axis of the instrument, (*b*) the axis of the bubble, (*c*) the line of collimation. Adjustment 1 (para. 72) which is a temporary adjustment and which has to be made at every set up of the instrument sets the axis of the instrument vertical if adjustment 2 is subsequently made. When adjustment 2 has been made then the axis of the bubble is correct and is at right angles to the axis of the instrument which is thus truly vertical and the footscrews *cannot* be used for any further adjustment of the collimation line and this is

important to remember. We are thus left with the line of collimation, which to be horizontal must be made at right angles to the axis of the instrument and this is done :—(*i*) by raising or lowering the diaphragm only (compare adjustment of theodolite for vertical collimation by diaphragm para. 66) or (*ii*) by raising or lowering the telescope to which the bubble is attached by means of the collimating screws and then correcting bubble by bubble screws only.

79. A description and method of adjustment of the foregoing instruments have been retained in this edition as it will be some years before they disappear entirely off the market and also it will be some years when they are so worn as to be deemed useless and be discarded. Any one conversant with the latest India pattern level will acknowledge that all previous types should be avoided as purchases and be as soon as possible relegated to a museum as they stand no comparison in ease of working, manipulation or saving in labour costs. Such a level is now described.

80. India Pattern Level.—(Fig. 35) (1). The main idea governing the design is that the level reading, distance and magnetic bearing are read by the observer at his position at the eyepiece of the telescope and by means of the internal focussing lens and manufacturer's fitment of the diaphragm in the optical axis of the telescope and also that the collimating line is actuated by a T piece, *one* means of adjustment, that of the bubble, is only required. Thus when the instrument is adjusted, all that is necessary is to bring the bubble (reflected in the prism) to the centre at the instant of reading. Errors of focus racking are nullified and stadia distances require no constant or one so small that it can be neglected.

(2.) Other minor features are those of complete standardisation of all parts, improved method of taking up wear equally on footscrews, taking up wear in the ball and socket joints of the stand, economy in weight* with due consideration for wind pressure, superior lenses giving clear readings up to 750 feet, locking arrangements on all temporary or permanent means of adjustment, slotted means of clearing compass of magnetic variation (*x*), telescope made of duralumin, clamp and slow motion screw to main axis and a pill box level (*b*) for first approximate setting up. (*See* figure 35).

(3). The micrometer screw (*m*) which actuates the T piece is graduated so that one turn gives a gradient of $\frac{1}{1000}$, 4 turns $\frac{4}{1000}$ or $\frac{1}{250}$ and so

* Weight of stand 11 lbs., weight of instrument in case complete 13 lbs. Total 24 lbs.

on and finally by using a 10-foot subtense bar or the whole length of the level staff, distances correct to within ·5% can be measured on the micrometer scale.

(4). The instrument is made in two sizes 9·5″ and 11·0″ focal length and is approximately about half the size and weight of the older patterns of the same accuracy. It is packed in a box in one piece and clamped down by spring cleats. Spare parts are contained in the box including a duplicate diaphragm. The whole is carried "rucksack fashion in a stout canvas case with webbing equipment.

(5). The instrument screws on to the stand.

(6). The minimum squad required would be one of two men, *viz.*, leveller and staff holder, and the maximum, using one staff only for back and fore, would be three men, that is, one, to carry the instrument from one station to the next and hold an umbrella for the observer when working. As no chain is required it will be seen that the instrument will pay for itself in a short time by its saving on labour bills estimated at Rs. 25 per mensem.

(7.) Finally errors and mistakes in the actual process of levelling will be those of the observer as the instrument is practically self-contained in every way. Nothing short of a blow sufficient to put the whole instrument out of commission will upset its adjustments.

(8). To set up and level Having screwed the instrument on the stand bring the pill box level *b* approximately to the centre, press home legs by the foot on the stirrups of the stand. Next bring the pill box level to the centre by means of the three footscrews. The instrument need not be rotated in doing this. Now bring the micrometer screw (*m*) below the telescope to O and while doing this it will be seen that the large bubble will be taking up a central position. When working, the micrometer is usually at or near its medial position. Turn the telescope on to the staff, focus, etc., and by means of the micrometer screw bring the bubble into the prism into its central position by watching it from the eyepiece. Read staff, say 4·36, and enter in field book, depress one stadia wire to a whole number, say 3·00, read the other stadia wire say 5·86, the distance is, therefore, 100 5·86—3 00) or 286 feet, enter this in the book. Next set the central wire to 4·36 when the bubble should return to the centre of its run (check). Finally read and enter magnetic direction as seen in the reader (*c*). The observer therefore does not move around his instrument and the reading is simultaneous with the position of the bubble. The foot-

screws are not touched in this levelling operation and are only a means to an end, that is quick setting. The line of collimation will be correct whenever the bubble is in the centre of its run, in any position of the telescope if the instrument is in adjustment.

(9.) (*a*). To adjust the instrument. Place the instrument midway between two pegs about 300 feet apart so that one footscrew points up and down the line and two footscrews are at right angles. Level up with the legs and pill box level (*b*) and bring micrometer screw (*m*) approx: to O. The telescope pointing up and down the line will be over one footscrew and with this footscrew bring the long bubble to the centre of its run and turn telescope end for end or through 180°. If the bubble is not in the centre, correct half by the one footscrew and half by the micrometer screw (*m*) and repeat in these two positions till perfect though in the first repeat it would be wise to place the telescope once only at right angles and correct any error of perpendicularity by the *other* two footscrews.

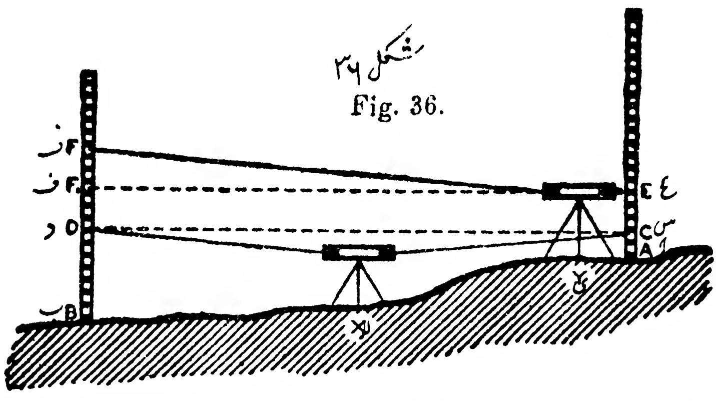


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Fig. 36.

(*b*). Having obtained a central position for the main bubble in the end to end directions read a staff on one peg and then on the other either (*i*) tapping one peg to the level of the other or (*ii*) noting the difference of readings, the bubble remaining on each occasion in the centre as previously adjusted temporarily.

(*c*). Remove the instrument to a position near one of the pegs so that a staff held on the peg will just miss the eyepiece of the telescope and do not touch the micrometer drum in doing so and in setting up have one footscrew as before pointing up and down the line. Roughly level up with pill box bubble (*b*) and next with the *one* footscrew bring bubble to centre, turn again telescope at right angles and being bubble to the centre by the other two footscrews and finally return to the position over one footscrew

and correct bubble by this footscrew only. Since the micrometer drum (*m*) has not been touched the bubble should be in the centre in an end for end position, if not, any small error should be corrected half by the footscrew and half by the micrometer screw as in (*a*) supra.

(*d*). Place the staff on the peg near instrument and read the "Height of Eye"* by looking through the O. G. end of the telescope. (*See* Fig. 36.) Remove the staff to the further peg and (*i*), if the two pegs had been tapped to the same height the instrument should read the same value as the Height of Eye, if in adjustment, or (*ii*) give the correct difference as noted in the operation *a*) supra If it does not, with the micrometer screw (*m*) make it read the same in one case *b*(*i*) or the correct difference in the other *b*(*ii*) and it will be found that the bubble has left its central position. Slacken the holding nut (S) for bubble adjustment and correct bubble by its two bubble nuts slackening one and tightening the other and observe its position when so corrected in the prism. Secure the adjustment by tightening screw (S).

Since the collimation line has been made horizontal and the tangent to the bubble parallel to this line it follows, that *when the bubble is brought to its centre by the micrometer screw* (*m*) the collimation line will be horizontal or in other words correct in any position of the telescope.

(*e*). Next loosen holding screw in knurled portion of the micrometer (*m*) and revolve the engraved portion in its sleeve to read O and tighten screw. For the purposes of simple levelling there is no point in having this zero to zero contact on micrometer absolutely correct as it must vary + and – a little according to the position and exactness of the setting of the pill box level (*b*).

(*f*). Complete the whole adjustment by correcting the pill box level by its own small adjusting screws or by dotting its position with a spot of Indian ink.

(*g*). It follows now that if the micrometer drum is approximatey O and the pill box level is made central by means of legs of stand first and footscrews next that a small turn of the micrometer screw (*m*), whilst actually in the position for observing, is sufficient to bring the bubble into its central position as seen in the prism and this is all the leveller will be called upon to do.

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* FOOTNOTE.—This "Height of Eye" method is in the opinion of the author the quickest and surest method of adjusting any level for line of collimation.

(10). (*a*). To use the gradienter on micrometer screw for laying out gradients proceed as follows. Having levelled up instrument, etc., as for levelling place the micrometer index to O, and if the bubble has left its central position bring it back by a suitable *footscrew.* Take the height of eye at instrument by means of a level staff or have a special target index rod made so that the index will slide up and down and be adjustable to the height of eye or collimation line. Set out the gradient on the micrometer drum one full turn equalling $\frac{1}{1000}$, 5 full turns $\frac{5}{1000}$ etc., and place the rod on pegs tapping the pegs up or down to meet the gradient line passing through the index or known height of eye on target rod or ordinary staff. The use of boning rods will be unnecessary.

(*b*). To use the gradienter as a subtense measurer, that is, for distances beyond the magnification and range of stadia readings, take a subtense bar of 10′ between targets or use targets on a 10′ level staff. Read the whole length of the staff as the central wire traverses from one end to the other or an intercept of 10 feet and on the micrometer drum read the revolutions and part revolutions, then D (distance) $= \frac{10,000}{\text{revs.}}$. Example let the readings on the drum be 0·00 to start with and 6·28 to end with then D or distance $= \frac{10,000}{6{\cdot}28} \doteq 1592$ feet ; if the first reading was + 5·28 and the last − 6·48 then D or distance $= \frac{10,000}{11{\cdot}76} = 850$ feet, etc. This subtense method of direct reading across a river, ravine or from spur to spur will be found very useful.

(11). The magnetic compass (C) is a separate fitment and can be kept in the box when not required. The reading index is adjustable up to 5° either way by (*x*) so that the bearings can be made to conform to true north instead of magnetic, saving a deal of office labour.

(12). The bubble can be read by the Zeiss prism attachment, or by Cooke's speculum mirror (Fig. 37) which foreshortens the ends and which is less expensive than the former. Probably for India the latter device is more suitable. Both read directly from the eyepiece. Some users find that the bubble can be read easily without requiring any prism device in which case the prism devices can be dispensed with and the cost of instrument consequently lessened.

80A. The above method of adjustment has been given as for some customary reason it was usually considered necessary to make the adjustment for perpendicularity of the axis of the bubble tube to the vertical

COOKE'S COMPOUND BUBBLE READING MIRROR

کک کی مرکب بلبلہ پڑھنے کا آئینہ

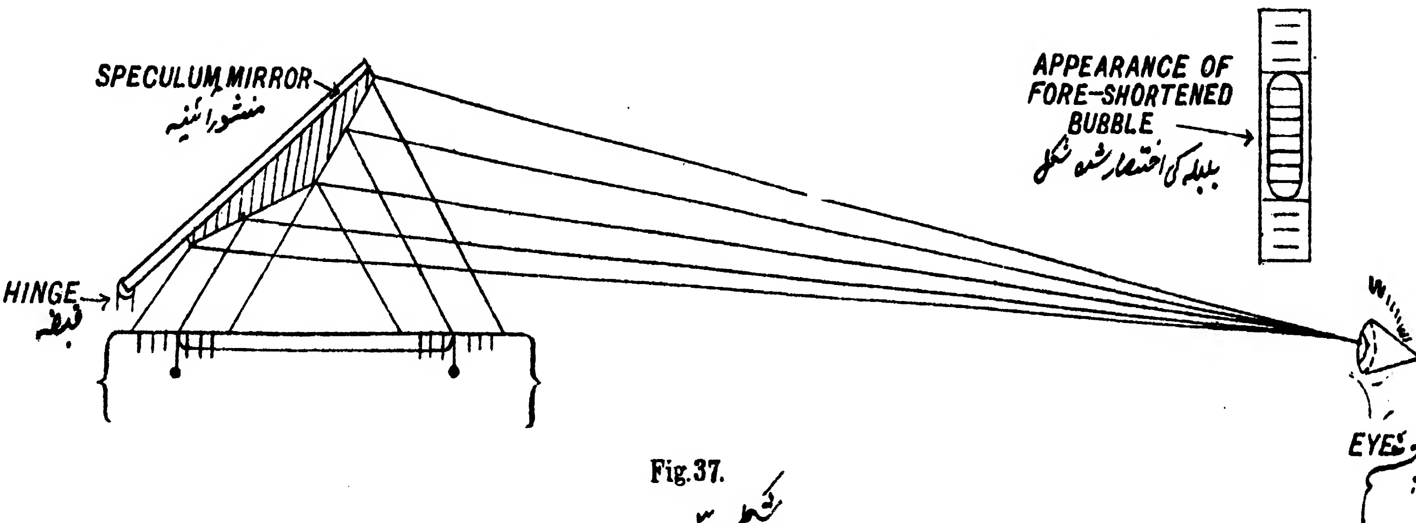

Fig. 37.

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axis so that the bubble when reversed or in any other position would show no divergence from its central position. **The necessity for this adjustment as an adjustment is a fallacy**, hence in adjusting the India Pattern Level the following procedure, if followed, is all that is required.

(*i*). Set up the instrument midway with one footscrew on the line joining two pegs fixed in the ground, set the micrometer to zero and level up the instrument by the footscrews and by means of the one footscrew on the line joining the pegs bring the bubble carefully to the centre of its run. Take a reading to a staff held on one of the pegs, reverse direction of telescope, bring bubble again to centre by the same footscrew and read to a staff held on the other peg. Tap down the higher of the two pegs till the reading on both pegs is the same when the bubble is in the centre of its run. The tops of these pegs will now be on the same level even if the instrument is out of adjustment.

(*ii*). Remove instrument and set up close to one peg so that a staff placed on the peg will pass about an inch from the eyepiece when the instrument is directed to the other peg. One footscrew must be in the line joining the pegs. Level up the instrument by the footscrews and take a reading to the staff on the near peg through the object glass. Now read to a staff on the further peg and if the reading is not the same as that on the near peg, make it so by means of the one footscrew under the telescope. If the bubble is not central make it so by means of the bubble nuts. Now the line of collimation is horizontal when the bubble is central and will be so for any distance away of the staff.

81. Other types of levels.—Variations of the types dealt with in this book are listed by all makers and the Farm Level (Fig. 38) and Reconnaissance Level (Fig. 39) are two very useful instruments when used for the purpose for which they are made. The American Binocular Level and the Zeiss Precise Level are not described in this book as these are large and delicate instruments used for Geodetic purposes only.

82. The Levelling Staff—Their number is legion, each with its own peculiarities of graduation but excepting this there are only two kinds, one, the target rod of America and the other, the self-reading rod or staff, as it is usually called. The Americans, for many years, claimed an advantage for the target rod but have recently, owing to improvements

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FOOTNOTE.—The above level is standardised with a 5" India Pattern Theodolite I. O. Specification No. 781 and that of the Tacheometric planetable equipment. Specifications for the above are by the author.

made in precision instruments, changed their views so that many of their foremost engineers prefer the self-reading staff. With the self-reading staff errors are compensating, work is accelerated, the surveyor alone is responsible for his mistakes or errors and its accuracy is acknowledged by the fact that most of the world's precise levelling is accomplished on the self-reading type. Level rods or staves are from 10 to 14 feet in length. The 10 and 12 "foot" staves are usually in one piece about 1¼ inches in thickness and 2¼ inches face, the face being countersunk for the graduation. The 14 "foot" rod like the Sopwith is collapsible. This collapsible style of rod has many disadvantages. It is heavy, swells with rain so that it is sometimes difficult to close or extend, and the staff man may ruin a whole day's work by not fully extending it to the spring catches, and this may remain unnoticed and certainly will, if the joint is not more or less in the field of view of the telescope. The springs also become weak and a slight jar allows one of the slides to drop. The disadvantages seem therefore to outweigh any advantages in length and portability. The Indian or Roorkee pattern staff is a simple straightforward staff and for this reason is largely used. The figures denoting full feet are in red and two rods can be clamped (clamps are supplied) so that the total length becomes one of 18 feet. However the best staff for the individual is the one he is used to. The G. T., Sopwith and the revised Roorkee pattern staves are illustrated in plate X. In the Roorkee pattern the upper edges of the bars or graduations are even numbers. 3·00 is the *top* of the red bar opposite the red figure 3.

83. The Tangent Clinometer.—*See* Chapter on Planetabling. Perhaps one of the most useful instruments to the topographical surveyor using the ordinary planetable and plain sight rule is the tangent pattern clinometer. The instrument consists of (*see* Fig. 40) a sight-vane and a peep-vane mounted perpendicularly on a bar at the end of which is a milled head screw which works against the bed plate. The bar is pivotted at the sight-vane end, and on the bar and parallel to it, is placed a level so that the bubble is moved by means of the milled head screw which raises or depresses the bar and thus elevates or depresses the line of sight through the peep-hole and the 0 division on the sight-vane. The height of the peep-hole is about 3½ inches above the bar and the length of the sight-vane is about 7 inches. The sight-vane is an inch in breadth and ⅜ of its breadth centrally is cut away so that objects can be viewed either against the left or right edge of this aperture.

The distance between the peep-hole and the centre of the sight-vane is 8 inches and the sight-vane from the centre upwards and downwards is graduated on the left side in degrees and on the right to natural tangents to an arc of 8 inches.

The use of the instrument is very simple. It is placed on the table and usually the right edge of the aperture, that for natural tangents, is brought on the object so that when the observer looks through the peep-hole the object is seen to be cut at or near a certain division of the scale. The bubble is now brought to the centre and a reading is taken ; let it be ·024 ·02 reading + ·004 by approximation.* This represents the natural tangent of the angle which multiplied by the horizontal distance taken off the plan and when corrected for curvature and refraction, will give the difference of height between the instrument and the object. Over distances up to 5 miles a properly-adjusted clinometer will give mean readings to within 5 feet. The distances in feet between the instrument and object observed is usually taken off a cardboard scale on which the curvature and refraction correction is also ruled at intervals.

84. To adjust the instrument.—With a theodolite or level at hand to set out a level line it is only necessary to adjust the bubble to the line of sight but as the instrument is generally used on topographical work with fixed stations and heights a simpler method suggests itself. The instrument is set up on a planetable over a known station mark with the height value given. To this known height is added the difference of height between the mark "in situ" and the height of the peep-hole when the height of the peep-hole is obtained. From the plottings on the table one or more other points are selected with given heights and as the horizontal linear distance is known so also is the correction for curvature and refraction.

Since difference of height between A and B = natural tangent of the angle between A and B × horizontal distance between A and B ± curvature and refraction (in this case since the object at B is observed to and the height of A deduced from B curvature and refraction is minus) thus the natural tangent of the angle is known. With the milled head screw make the instrument read this natural tangent and if the bubble is not in the centre of its run then correct it by the bubble nuts.

* FOOTNOTE.—The College Pattern has the top of the elevating or depressing screw graduated by which the eye approximation becomes a reading that is the quantity ·004 is found on the screw.

Example —Height of station A = 1,440
„ „ „ B = 1,765
„ „ „ C = 1,420

and distance A to B = 10,000 feet and A to C = 6,000 feet. Height of eye = 4 feet and therefore height of instrument at A = 1,444. By calculation the natural tangent of B = + ·032, and of C = − ·004 and if the instrument does not read these values the bubble is incorrect, so elevate or depress the peep-hole to obtain these values and correct the bubble accordingly.

In using a tangent clinometer it should be lifted by its base, ***never*** by its vanes. The vanes should be perpendicular and as a test the distance between the peep-hole and the sight-vane should be 8 inches directly across. In choosing a tangent clinometer select one in which the bubble is fairly long and sensitive though not too much so and which has the peep-hole just large enough to admit of no parallax. A large peep-hole admits of a great deal of latitude in observation in that the object cannot properly be located at a definite reading.

In the example the value ·032 is read as 03 line and an approximation of ·002 above it. This approximation becomes a simple one with practice but there exists a device by which the peep-hole is raised by a micrometer screw which makes such an approximation more accurate.

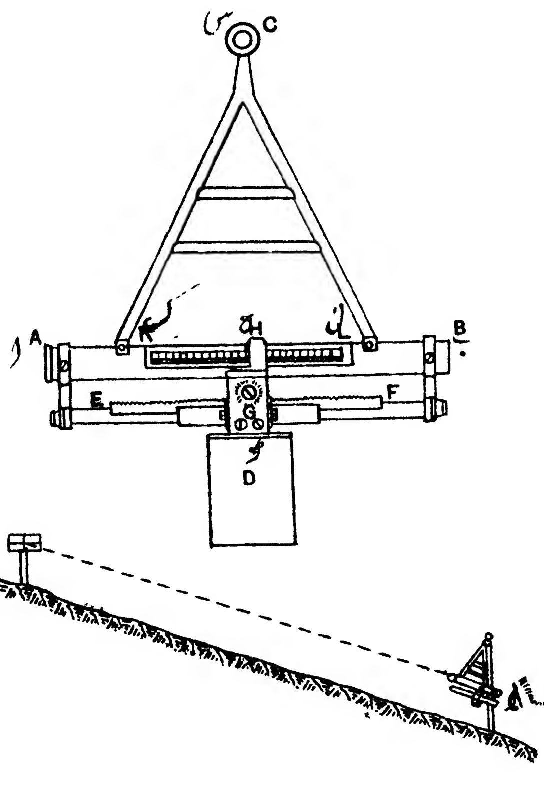
85. The Abney Clinometer or Level consists of a sighting tube with one horizontal wire and a piece of reflecting glass placed so that one edge is along the vertical sight line and so that on looking through, half the aperture is filled up by the mirror and half is vacant for viewing the object.

To this tube is fixed a graduated arc and vernier. The vernier is turned by a milled head screw to which is also attached a bubble. This bubble is so placed that its reflection is cast down on to the mirror. When the line of sight is level the bubble will be seen in the centre of the line of the mirror and the vernier will read 0°. A little thought will make it evident that, if the line of the sight is inclined and the milled head screw is turned till the bubble becomes level so that its reflection is seen, the vernier which is also moved by the milled head screw will give the angle of elevation or depression and in some instruments also the gradient and the value to be used in reducing a chained distance to the horizontal. This little instrument which is not more than 4 inches by 2 inches is less cumbersome than the ghat tracer, is just as accurate if not more so, and has other uses as well. No engineer should be without an Abney clinometer

or level when working on preliminary alignments. To adjust the Abney level it is probable that a level or theodolite is necessary in order to obtain a level line and then on sighting with the Abney level if the vertical arc is set at 0° and the bubble is not in the centre the bubble screws are to be used to correct the bubble or an index error noted. Another method will suggest itself when the heights of two known points are given and the tangent of the angle is computed as in the next paragraph. The *De Lisle* reflecting level is also a quick and accurate method of laying down preliminary gradients for hill roads, railways, etc.

86. The Ceylon Ghat Tracer.—This is a useful instrument for carrying out rough preliminary survey of a hill route of any required gradient (Fig. 41.)

Fig. 41.



It consists of a hollow metal sighting tube AB fitted with an eyepiece at one end and cross-wires at the other. The tube pivots round the

point C, which is held suspended from an upright staff. The required inclination is given to the sighting-tube by means of the weight D, which is capable of motion along the rack EF by means of the screw G. H is an index which moves along a graduated scale of gradients KL marked on the body of the tube.

Thus, supposing a gradient of 1 in 43 has to be laid out along a hill slope. The weight D is moved along until HK reads 43 on the scale. A man with a sight-vane, which is set at the height of the axis of the sighting-tube above the foot of the suspending staff, is then sent along the hill-side to a convenient distance, usually from 50 to 60 yards, until the place is found where the cross-wires intersect on the centre of the sight-vane. The foot of the vane is then resting on a point, from which the slope down to the observing point is one of 1 in 43. The assistant drives a peg in here, to which the surveyor advances and repeats the operation. In the figure the sight-vane is shown as turned through a right angle.

87. The Aneroid Barometer.—The mechanism of an aneroid barometer is explained in most books on physics and only the precautions to be taken in registering readings and the requisite formulæ are here given.

A good working size of instrument is a 5 inch with a range of 5,000 to 6,000 feet. Aneroids must be carefully handled and carried and are really only true within a certain limit when the readings are simultaneous or are taken at short intervals of time. They are compensated for internal temperature of instrument but great reliance should not be placed on this and they should be compared as often as possible with a standard barometer. On most aneroid barometers the zero of the altitude scale is at 31 inches of the scale corresponding to the mercury column. Aneroids when compared with a standard mercury barometer usually have an error which can be considered an index error or the screw at the back of the box can be turned to regulate the pointing of the needle. Heights to within 10 feet are possible with great care. To obtain better results a separate aneroid should be retained at the base and readings recorded every half hour to compare such with the aneroid in use on the journey.

Aneroids are more reliable when used on uphill journeys as the atmospheric pressure decreases and the spring relaxes; on the other hand when the reverse is the case and the tension on the spring increases the instrument takes some time to settle down. Readings must always be taken with the instrument at each station either held vertical or horizon-

tal and it should be tapped gently before reading to make sure the chain gear is working properly.

There are several corrections necessary in barometric levelling such as temperature, changes of instrument and stations, corrections for latitude and decrease of gravity on the vertical, but with the aneroid, and for the ordinary purposes of the engineer, as the aneroid is compensated for internal temperature of instrument only the correction for air temperature at different stations will be considered, that is, if t is the temperature of the instrument at the lower station where the instrument reads H inches and t' the temperature of the higher station where the instrument reads h inches then according to one formula we get (i) D the difference in height $= 60158{\cdot}6 \; (\log H - \log h) \times \left(1 + \frac{t + t' - 64^\circ}{900}\right)$

(ii) due to Airy ; $D = 62759 \,(\log H - \log h) \times \left(1 + \frac{t + t' - 100^\circ}{1000}\right)$; that is the difference in two altitude readings is corrected for temperature by $\frac{1}{1000}$ part for every degree the sum of the temperatures when the sum exceeds 100° F.

For rough calculations the following might be useful :—

(iii) $D = 55000 \frac{H - h}{H + h} + \frac{1}{500} D$ (for each degree of mean temperature) above 55° F.

(iv) For approximate values only, $D = 55000 \frac{H \mp h}{H + h}$

Example let $H = 30{\cdot}00$ inches

$h = 28{\cdot}00$ inches

$t = 90^\circ$.

$t' = 64^\circ$

Then by formula (i) we obtain—

$D = 60158{\cdot}6 \,(1{\cdot}47712 - 1{\cdot}44716)\left(1 + \frac{t + t' - 64^\circ}{900}\right)$

$= 60158{\cdot}6 \times {\cdot}02996 \times (1 + \frac{1}{10})$

$= 1982 \cdot 6$ feet.

By formula (ii) $D = 62759 \times {\cdot}02996 \,(1 + {\cdot}054)$

or $\log D = \log 62759 + \log {\cdot}02996 + \log 1{\cdot}054$

$= 4{\cdot}79775 + \bar{2}{\cdot}47654 + 0{\cdot}02284$

$\therefore D = 1982{\cdot}1$ feet.

By formula (iii) $D = 55000 \times \frac{2}{29} + \frac{1}{500} \times D \times 22^\circ$

$= 1895{\cdot}2 + \frac{22}{500} \times 1895$

$= 1895{\cdot}2 + 83{\cdot}4$

$= 1978{\cdot}5$

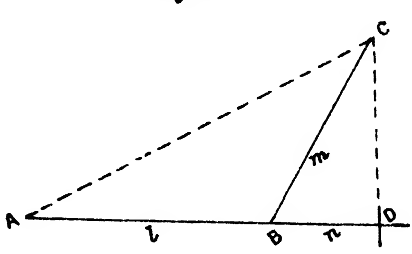
By considering $D = 1978 \cdot 6$ we can bring this result still closer by substituting the value $1978 \cdot 6$ in the second part of the equation and obtain $1895 \cdot 2 + 88 = 1983$ feet and again obtain the limiting value 1984 feet.

The best use the aneroid can be put to is to find a *difference* in level between two stations rather than it be used as an independent height recorder.

88. The planimeter is a mechanical integrator and is used to find out the area of any irregular figure. The best known is that of Amsler (Fig. 41). It consists of two arms, one the tracing arm A to which the recording wheel D with dial G and tracing point is attached and the other the main arm C which is pivotted to the tracing arm and is also pivotted to the paper by means of the needle-point pressed into the table on which the instrument rests.

When the instrument is placed on the paper ready for use there are three points of contact, one the tracing point, two the rim of the recording wheel and three the needle point. To the central pivot B is attached a sleeve into which the tracing arm slides which enables the instrument with reference to the length of the tracing arm to be set to some particular index and the distance between the tracing point and this pivot multiplied by the circumference of the recording wheel is equal to the area circumscribed in units to which the bar is set when the needle-point is fixed *without* the area to be circumscribed.

Fig. 43.

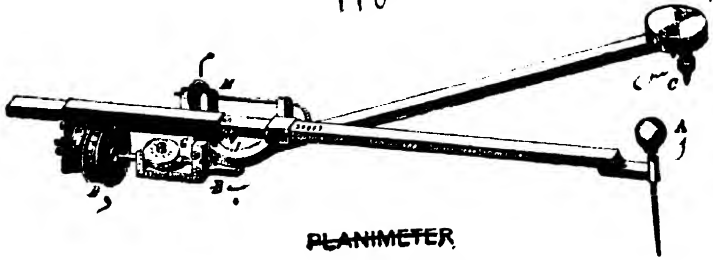


The recording wheel D. in fig. 42 is divided into 100s of its circumference and a vernier gives the 1000ths. By means of a wormed wheel a dial indicates the number of revolutions made by the wheel. If for instance the instrument was set to 0 and the tracing point A was taken along the periphery of a figure you might obtain the following reading $1 \cdot 967$ and this would be obtained as follows :—1 on the dial, 96 on the recording wheel and 7 on the vernier and the area of the figure would be $1 \times 1 \cdot 967$ (1 = distance A B in terms of the unit to which the bar is set).

Again when the pivot C is within the figure to be circumscribed by the tracer A (Fig. 43) it will be seen that in certain positions the wheel

Fig. 42.

شکل ۴۲



PLANIMETER

سطح پیما

will not register and this is when the angle ADC is a right angle so that besides the area as given by the recording wheel, an area equal to a circle of which AC is radius, has to be added. This circle is called the zero circle of the instrument and $AC^2 = AD^2 + CD^2$

$$BC^2 = BD^2 + DC^2$$

AD^2

$$\therefore AC^2 = \cancel{AB^2} + BC^2 - BD^2$$

$$\text{or} \quad AC^2 = AB^2 + BD^2 + 2AB,BD + BC^2 - BD^2$$

$$= l^2 + m^2 + 2ln = \text{radius}^2.$$

$$\therefore \text{ area of zero circle} = (l^2 + m^2 2ln)\pi$$

The area of the zero circle is computed by the maker, for each instrument and is engraved on the top of the bar over each index or setting and nearest to the setting for which it is intended.

(*a*) To take out an area when the pivot C is without the area. First roughly run the tracer A along the periphery to make sure every point on it is reached without the instrument being awkwardly placed and then press in the needle point C and add the small weight at C to steady it. Start from any point on the periphery and record the reading, let it 2·676. Move the tracer carefully along the periphery in a *clockwise* direction and return to the starting point and let the reading be 4·593. The difference of reading multiplied by the length of the bar l will equal the area. If the bar had been set at index 10 sq. inches then the area in example would be (4·593—2·676) 10 = 19·17 sq. inches.

If the motion of the tracing arm is *clockwise* then the first reading or lesser reading is always subtracted from the second or greater reading to get the difference and it is convenient to remember this. The dial must be watched to see when a 0 is passed in which case the second reading is in 10,. Example :—Instrument is turned in a clockwise direction first or starting reading is 8·930 and closing reading is 0·960. It is evident for any area to be enclosed 0·960 clearly means 10·960 but it might also mean 20·960 that is that the dial registered two 0, and so forth. Again if the dial passes over one 0 and then has a retrograde motion coming back and repassing a 0 then these cancel.

(*b*) When the area to be circumscribed is large such that the pivot C is placed *within* then the same procedure is adopted as before but the area of the zero circle or the constant to which the bar is set, is added to the difference of readings. If this constant or area of zero circle had been 22,196 engraved on the bar just above and next to the index line for 10 sq. inches then in the example given above since this area must be added

we get $(22\cdot196+4\cdot593-2\cdot676)\ 10=241\cdot13$ sq. inches, that is, an area of 19·17 sq. inches over and above the area of the zero circle of 221·96 sq. inches = 241·13 sq. inches.

(*c*) It will be noticed that the sleeve into which the tracing arm slides is fitted with a clamp and slow motion screw M and their uses are not only to get the index lines to coincide so much as to adjust the instrument to give true values for areas of drawings and surveys on paper which have contracted or expended under exposure. Every survey when it is plotted or projected should have ruled squares or graticules of certain dimensions. These squares or graticules become warped perhaps (*see* paragraph 9) but according to the original plotting to scale they must contain a certain area. Let us consider a survey and take a square 8 inches by 8 inches equalling an area of 64 sq. inches. If the planimetre is set to index 10 and the pivot point C is without the area the difference of reading should be 6·400; but if the paper has contracted the instrument might give 6·390. Since the area is 64 sq. inches the instrument must be made to read 6·400 and the rule is to *lessen* area *lengthen* bar or *vice versa* and in this case the bar would be shortened. When the instrument is thus adjusted to the paper all areas for that paper will be true areas.

89. Copying Plans, Maps, etc., by hand.—There are several methods of doing this when the copy is to be the same size as the original, such as placing the plan to be copied with a sheet of paper over it on a tracing glass, placed in such a position that a strong light may fall on it *from behind* or *underneath* and then tracing it off. Or by placing a sheet of thin paper, having its underside blackened (by rubbing finely powdered black lead or a soft lead pencil over it), on the sheet of paper that is to receive the copy, the original being placed over both, and the whole made steady by placing weights thereon: all the lines of the copy must now be carefully passed over with a fine tracing point, and with a pressure proportionate to the thickness of the paper; the paper beneath will receive corresponding marks forming an exact copy, which may afterwards be inked in. All these systems of copying hurt, in a more or less degree, the original drawing. Tracing cloth is now used in engineers' offices very largely. This cloth is rendered sufficiently transparent to admit of very fine detail work being traced off, and will permit color being applied. It is as well however, to apply the color on the reverse side of the cloth, as it is difficult to get it to lay evenly on the cloth. Such unevenness in a flat shade scarcely shows when seen through the tracing cloth. Tracing

paper was formerly much used, but has now been entirely superseded by tracing cloth. In India, tracing paper soon gets dry and brittle, and will not stand handling. When the drawing is to be reduced or enlarged, the pantagraph, eidograph, the method of copying squares, or the lens must be resorted to.

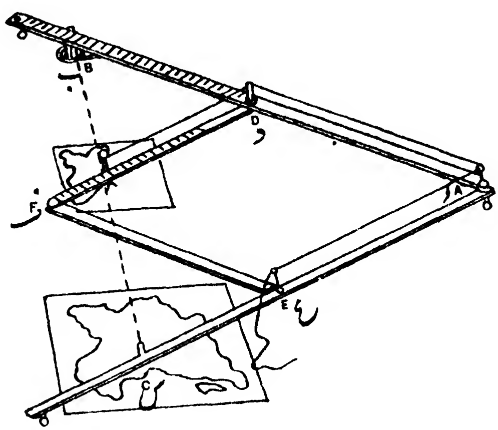
90 (*a*) **The Pantagraph** consists of four rulers, AB, AC, DF and EF, (*Fig.* 44), made of stout brass. The two longer rulers, AB and AC, are connected together at A, and have a motion round it as a centre. The two shorter rulers are connected in like manner with each other at F, and with the longer rulers at D and E, and being equal in length to the portions AD and AE of the longer rulers, form with them an accurate parallelogram, ADFE in every position of the instrument. Several ivory castors support the instrument, parallel to the paper, and allow it to move freely over it in all directions. The arms AB and DF are graduated and marked $\frac{1}{2}$, $\frac{1}{3}$ etc., and have each a sliding index, which can be fixed at any of the divisions by a milled-headed clamping screw, seen in the engraving. The sliding indices have each of them a tube, adapted either to slide on a pin rising from a heavy circular weight, called the fulcrum B or to receive a sliding holder with a pencil or pen, or blunt tracing point, as may be required.

When the instrument is correctly set, the tracing point, pencil and fulcrum will be in one straight line, as shown by the dotted line in the figure. The motions of the tracing point, and pencil are then each compounded of two circular motions, one about the fulcrum and the other about the joints at the ends of the rulers upon which they are respectively placed. The radii of these motions form sides about equal angles of two similar triangles, of which the straight line BC, passing through the tracing point, pencil and fulcrum, forms the third side. The distances passed over by the tracing point and pencil, in consequence of either of these motions, have then the same ratio; therefore the distances passed over, in consequence of the combination of the two motions, have also the same ratio, which is that indicated by the setting of the instrument.

The diagram represents the pantagraph in the act of reducing a plan to a scale half the original. For this purpose the sliding indices are first clamped at the division upon the marks marked $\frac{1}{2}$; the tracing

point is then fixed in a socket at C, over the original drawing; the pencil is next placed in the tube of the sliding index upon the ruler DF, over the paper to receive the copy, and the fulcrum is fixed to that at B, upon the ruler AB. The instrument being now ready for use, if the tracing point at C be passed delicately and steadily over every line of the plan, a true copy, but of one-half the scale of the original, will be marked by the pencil on the paper beneath it. The fine thread represented as passing from the pencil quite round the instrument to the tracing point at C, enables the draftsman at the point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another and thus to prevent false lines from being made on the copy. The pencil holder is surmounted by a cup, into which sand or shot map be put, to press the pencil more heavily on the paper, when found necessary.

Fig. 44.

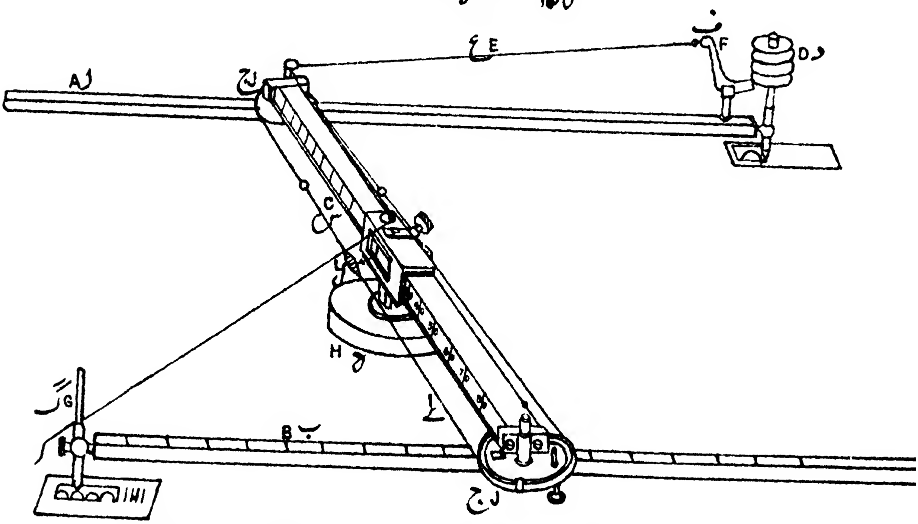


If the object were to enlarge the drawing to double its scale, then the tracer must be placed upon the arm DF, and the pencil at C and if a copy were required of the same scale as the original, then the sliding indices still remaining at the same divisions upon DF and AB the fulcrum must take the middle station, and the pencil and tracing point those on the exterior arms, AB and AC, of the instrument. The instrument should be tested by means of a line at C and its ½, ⅓ lengths, etc., when reduced, before commencing work on a map.

91. The Eidograph.—The Eidograph which is represented in the accompanying engraving, (Fig. 45) is a far superior instrument to the pantagraph being more exact in its work, and not so limited as regards ratio of reduction.

The point of support when the instrument is at work is a heavy weight shown at H, from the underside of which three or four projecting needle points fix the instrument firmly to the drawing paper. Springing from this weight is a short standard or fulcrum, attached to a sliding-box, K, in which slides the centre beam, C, and to any part of which it may be clamped by means of a clamping screw.

Fig. 45.



At the ends of the central beam are two pulley wheels, JJ, the centre pins of which revolve in sockets at the ends of the beam. Two steel bands, I, I, attached to the pulley wheels, give them an exactly simultaneous motion, and these bands have a screw adjustment, L, by means of which they may be tightened.

The arms A and B are made to slide through boxes under the pulley wheels, and may be clamped at any proportion of their lengths in the same manner and the central beam, C, may be made to slide and clamp in the box K.

The arm B carries a tracing point, G, and the arm A carries a pencil point, D. The pencil holder may be raised by means of a cranked lever F, attached to a cord, E, which passes over the centre beam, and thence the tracing point, G.

The two arms and the beam are divided into 200 equal parts which are figured 100 each way from the centre, and may be read to 1000th by means of the verniers on the sliding boxes.

There is a loose weight which may be attached when the instrument has been set, and the object of which is to steady it when there is a great difference in the proportions to which the instrument is being worked.

It will be observed that the pulley wheels give the easiest possible motion: these wheels should be of exactly equal diameter, and as they are turned in a lathe, this equality may be obtained to the greatest perfection.

To bring the instrument into adjustment let the verniers be set to zero, which will bring them to the centres of the arms and of the central beam; place the arms at right angles to the beam, as near as you may guess, and make a mark with the tracer and pencil point, and turn the instrument round so as to bring the pencil point into the mark made by the tracer; by doing this you will make the tracer move exactly to the mark previously made by the pencil, if the instrument is in adjustment; if otherwise, the error in difference should be bisected, and the adjusting screws on the band should be moved until the tracing-point comes exactly into the bisection.

92. Copying by squares.—To explain the method of copying by squares let the annexed engraving (Fig. 46), represent a plan of an estate, which it is required to copy upon a reduced scale of one-half. The copy will therefore be half the length and half the breadth, and consequently will occupy but one-fourth the space of the original.

Fig. 46.

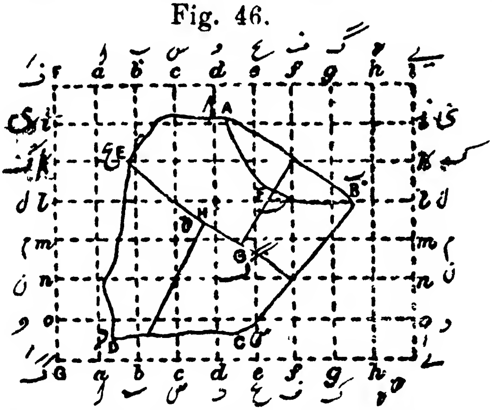
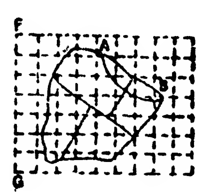


Fig. 47.



Draw the lines FI, FG at right angles to each other; from the point F towards I and G, set off any number of equal parts, as F*a*, *ab*, *bc*, etc., on the line FI, and F*i*, *ik*, *kl*, etc., on the line FG, from the points, in the line FI, draw lines parallel to the other lines FG, as *aa*, *bb*, *cc*, etc., and from the points on FG, draw lines parallel to FI, as *ii*, *kk*, *ll*, etc., which being sufficiently extended towards I and G, the whole of the original drawing will be covered with a net-work of small but equal squares. Next draw upon the paper intended for the copy, a similar set of squares, but having each side only one-half the length of the former, as is represented in Fig. 47.

It will now be evident that if the lines AB, BC, CD, etc., *Fig.* 45, be drawn in the corresponding squares in *Fig.* 46, a correct copy of the original will be produced, and of half the original scale. Commencing then at A, observe where in the original the angle *a* falls, which is towards the bottom of the square marked *de*. In the corresponding squares therefore, of the copy, and in the same proportion towards the left hand side of it, place the same point in the copy: from thence tracing where the curved line AF crosses the bottom line of that square, which crossing is about two-fifths of the width of the square from the left hand corner towards the right, and cross it similarly in the copy. Again, as it crosses the right hand bottom corner in the second square below *de*, describe it so in the copy; find the position of the points similarly where it crosses the lines *ff* and *gg*, above the line *ll*, by comparing the distances of such crossings from the nearest corner of a square in the original, and similarly marking the required crossings on the corresponding line on the copy. Lastly, determine the place of the point B, in the third square below *gh* on the top line; and a line drawn from A in the copy, through these several points to B, will be a correct reduced copy of the original line. Proceed in like manner with every other line on the plan, and its various details, and thus will be obtained the plot or drawing, laid down to a small scale yet bearing all the proportions in itself exactly as the original.

It may appear almost superfluous to remark that the process of enlarging drawings, by means of squares, is a similar operation to the above excepting that the points are to be determined on the smaller squares of the original, and transferred to the larger squares of the copy. The process of enlarging, under any circumstances, does not, however, admit of the same accuracy as reducing.

It is also as well to remember, that when a drawing is reduced to half the scale, the size is diminished to ¼th, or if the scale is ⅓rd of the original, then the size will be ⅑th: and *vice versa*, if the drawing is enlarged.

93. Copying by the Lens.—A suitable lens fitted to a camera used to reduce plans by replacing the ground glass with a sheet of clear glass covered by fine tracing paper. The drawing or plan to be reduced should be pinned on a vertical stand in strong sun-light, and when focussed to the required scale the lines thrown on the tracing paper can be followed with a fine pencil. The process is trying to the eyes of the operator, but is useful when only one copy of the reduction is required.

CHAPTER IV.

LEVELLING.

94. Levelling.—Some writers object to levelling being considered a branch of surveying as it is argued that surveying deals solely with the plan of the earth's surface, whereas levelling has to-do with the sectional portion of it. From an engineering point of view levelling is of first importance, and as this book has been written for the engineer rather than the reconnaissance or military surveyor it has been incorporated as a branch of surveying.

The object of levelling is to find; (1) how much one point on the earth's surface is higher or lower than another given point; (2) to fix a point or points of a certain height above or below or on a level with the certain given point.

95. Datum.—All elevations are referred to some imaginary surface which is assumed to be of zero level and the mean surface level of the sea is the most convenient datum to assume. This is not an invariable rule, as if relative heights are only required of a certain small detached area some other conveniently assumed datum may be accepted; the assumed datum surface in this case should always be lower than any possible elevation found in the area for convenience. The *datum* of the English Ordnance Survey is the mean sea level (M. S. L.) at Liverpool and of the Survey of India the M. S. L. at Karachi.*

96. Bench marks are points of reference whose heights or elevations above the assumed datum are found and known. These points should be carefully selected and distributed according to the needs of the country. In a city bench marks would be at closer intervals than in the country. Standard bench marks are usually obtained by precise levelling under the ægis of a Government and such values are found along trunk roads and railways where the going is easy, the grades flatter and clear sights are obtainable. Some authorities prefer to have their B. Ms. engraved and fixed. This system of marking is not always safe in a semi-civilised country where a brass disc or a stout nail is of some local value and hence the ultimate destruction of such marks. It is best under such circumstances

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* It is generally understood to be the M. S. L. at Karachi, but actually the reduction of the Indian levels connect the level net with M. S. L. at 9 stations, Karachi being one.

to select an unplastered slab which is also well protected from traffic* and to carefully describe its position and note its measurements relative to near and well recognised objects. Bench marks need not necessarily be at or near ground level, a cornice or other mark can be selected and measured to by means of the staff held upside down.

97. **Theory of levelling.**—When a level has been set up and the line of sight made horizontal, it is required to find how much above a certain point in the plane of sight this object is.

To obtain the height of the plane of sight and then to transfer its value to another point on the earth's surface, some other instrument besides the level is necessary. This instrument is known as the *levelling staff* (or self-reading rod) and is a piece of well seasoned wood painted and graduated to decimals of a foot or metre (*see* para. 82). The reading to a staff held on the point the reduced level of which is known, is the *backsight*, and the reading to a staff on the point, the value of which is required, is the *foresight*. Owing to errors in graduation, etc., it is customary to use one staff only and the use of two staves is not advised unless they have both been thoroughly tested to give the same readings at different parts of the staves each to each. The co-efficient of expansion in staves used in precise levelling for different temperatures should be known and recorded.

98. **A level surface** is not a horizontal surface but a curved surface which is at right angles to the plumb line at any point in that surface, so that a level line is not a straight line but a curved line and would conform exactly to the earth's surface were that surface a perfectly regular one. Compare the surface of a large still lake which is a level surface and yet not a horizontal one. The line of sight is a horizontal line and is a tangent to the level surface which passes through the observer's eye and hence a correction for curvature would have been necessary if it were not for the short lengths taken between staves when curvature has no effect (compare reciprocal levelling) and also as the instrument is invariably placed midway between the staves when the allowance for curvature and also refraction is cancelled and eliminated.

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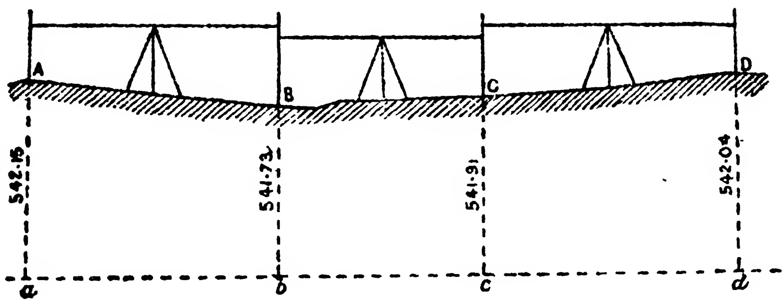
* The recently published volume on levelling of precision issued by the Survey of India on page 64 points out that bench marks along railways and roads are not altogether satisfactory owing to the continual vibration set up by traffic, and although the leveller might work along the railway or road, bench marks are set up at a distance.

99. How to Level.—The following explanation will show how levelling is performed. Suppose we want to know the ups and downs of a line along which a road or canal is to be run. We should always start from

Fig. 47.



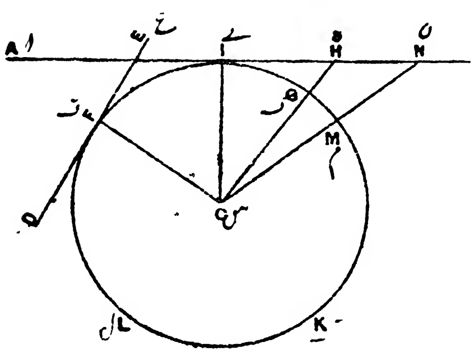
some permanent point, such as the edge of a well or step of a building, whose height and position will not vary, and we set up the instrument between A and B, and make the telescope truly level; then putting the staves on A and B, (*Fig.* 47) say, that when we look at them through the telescope, the hair cuts them at 3·90 and 4·32 respectively, then we know at once that point B is 4·32—3·90 or 0·42 below A. We then remove the level to between B and C, and find that the two staves placed on these two points read 4·90 and 4·72, thus showing that C is 0·18 above B, or in consequence 0·24 below A, and so on we can move to between C and D, etc., and find the levels of any points with reference to A. If also we know the height of A, or any of the points above the mean sea level at Karachi, which is the datum to which all levels should be reduced, we can reduce the levels of all these points to that. Thus say A is known to be 542·15 above the mean sea level. This is called its *reduced level*, then that of B will be 542·15—0·42, or 541·73. Similarly that of C will be 541·73 + 0·18, or 541·91.

If now a line be drawn to represent the M. S. L. at Karachi, as *a*, *b*, *c*, and the distance *ab*, *bc*, measured at AB, BC, etc., mark off the vertical offsets *a*A = 542·15, *b*B = 541·73, etc., can be laid off, and the line A B C D plotted, which will be a correct longitudinal section of the line of road, etc., required, if the staves have been put up as they should be at the points where the slopes change.

This is really the whole business. *a*, *b*, *c*, *d*, is the datum line, a permanent point such as A, on the well, is called a bench mark, and reduced level, the other term, has been explained.

100. Curvature of the earth and refraction.—This has an effect on the observations, so must be considered. In the figure if the instrument is supposed set up at I, and staves at unequal distances from it, as G and M, then the heights read off on the staves will be the unequal ones GH and NM, which, as the points G and M are truly level with I, will give an error.

Fig. 48.



This error is, however, modified to a certain extent by the optical deception arising from the refraction from the air which acts in the opposite direction.

A Table, No. II. of the combined error is given in the appendix at the end of Part II, and as the greatest distance at which the staff can be read by the best levels is only about 530′, it will be observed that the error ·00598 is very small, and may be safely neglected in all but the most exact and scientific observations.*

The extreme case, moreover. in which the error is ·00598, a measure in itself barely readable on the staff, only occurs in the very unusual condition when one staff has to be read close to the instrument and the other at 500 feet off. Had one been at 400 and the other at 500, the error would only have been the difference of the error at both readings, *i.e.*, ·00598—·00383 or ·00215, and if the distances of the two staves from the instrument are even the errors of course cancel. The errors, caused by the instrument not being in perfect order, are much greater than those caused by curvature and refraction; but these also are eliminated by working with the instrument midway between the staves, as it is evident that even if the telescope points up or down instead of level, provided the bubble is in the same position for both readings the error is the same, and we get correct *difference* of level which is the result sought.

101. The following are the different classes of levelling:—

(1) **Precise levelling** for the establishment of bench marks (B. Ms.) over a large tract of country. *Examples*—Great Trigonometrical levelling in India, Ordnance levels in the United Kingdom, France, etc., Geodetic

* As a rough rule $C = \frac{2}{3}$ (Miles)² and Refraction $= \frac{C}{7}$ and thus for 20 miles $C = \frac{2}{3}(20)^2 = 266'$ and $R = \frac{266}{7} = 38'$; therefore C − R or the combined result $= 228'$.

levelling in the United States of America. (2) **Check levelling** to find the difference of height **between two points.** This is also known as *differential* levelling. (3) **Profile or longitudinal levelling** in which the object is to find the exact slope, trend or the section of the ground from which may be worked out the grades of a railway or the fall or slope of a canal. (4) **Cross-section levelling** in which the object is to supply a further series of sections at right angles to the longitudinal levelling so as to determine the general cross-slope of the ground or the bed of road, railway or canal and for the estimation of cutting and filling.* (5) **Flying levels** for approximate elevations. (6) **Reciprocal levelling** to obtain the difference of height between two points which are separated by a natural obstacle like a river where it is impossible to obtain an intermediate set up of instrument.

102. Precise levelling, etc.—This treatise is designed more for the engineer than the geodetic surveyor and therefore no attempt will be made to describe this class of levelling as it is a special branch requiring special precautions and methods of error distribution. Some of the features of the corrections† applied are as follows—for deflection ot plumb line due to the attraction of mass—effect of sun on the spirit bubble—personal error accumulation in one direction so that sections are levelled in an inward and outward direction—correction for bubble divisions, etc. A word might be said concerning the limit of error or the accuracy to aim at in first class levelling. If error in feet $=$ Constant $\sqrt{\text{distance in miles}}$ is accepted as a working formula, then for precise levelling $C=0{\cdot}02$ is considered a fair average constant so that the permissible error in 9 miles $=0{\cdot}02\sqrt{9}=0{\cdot}02\times3=\cdot06$ feet; for 100 miles it would be $\cdot2$ of a foot, etc. In ordinary levelling 5 times this amount is permissible or C might be taken to equal $0{\cdot}1$.‡ As instruments are perfected it is quite possible that this constant will be too large.

Check longitudinal and cross-section levelling are fully explained in the field book and the student, engineer or surveyor should have no difficulty whatsoever in following out the procedure advocated and recording them in a neat and proper manner.

* In undulating ground two 10 foot staves clamped together making in all 19 feet will expedite work considerably.

† It would be perhaps more correct to say that the system of observing has been designed to cancel suspected causes of error. The causation of such error is still under investigation.

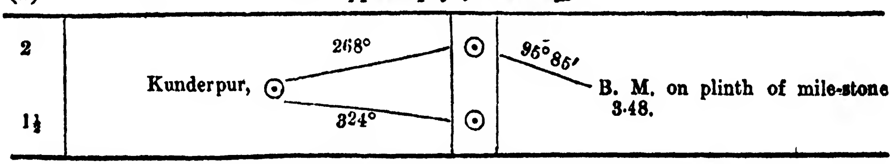
‡ If a leveller levels back over his line as a check the distance will be half and not the whole for finding the error as certain errors are compensating.

103. Levelling Field Books.—Many forms of field books are in use, and an experienced leveller will generally prefer his own. The two forms in most general use in these Provinces are—1*st*, the pattern adopted by the late Col. Dyas, R. E., first tried on the Sutlej Canal Project and now adopted generally for the Irrigation Department, and 2*nd*, an improvement on the English pattern. A specimen of both is here given, and also the latest pattern as now used at the Thomason College. It is to be noted that the numbers of the stations refer to the positions of the staves and not to those of the instrument.

(*a*) CANAL PATTERN.

No of back station	BACK.		Distance from instrument to each station.	FORE		DIFFERENCE		Reduced level of back station.
	Reading.	Bearing.		Bearing.	Reading	Rise.	Fall	
1	4 56	7°	300	187°	5·34	...	0·75	451·42 R. L. of G. T. S.
2	6·18	7°	300	187°	5·54	0·64	...	451 28.
3								

(*a*) *Opposite page for Survey.*



Station 1½ is between 1 and 2, where the instrument is set up.

(*b*) RISE AND FALL METHOD.

Station	Back	Intermediate.	Forward.	Distance.	Bearing	Rise.	Fall.	Reduced Levels.	Remarks.
1	4·56				187°			500·00	R. L. of starting point.
		5 34					0·78	499·22	Bench mark No 1 (G. T. S.).
2	6·71		4·21	500	172°	1·13		500·35	
		4 30		800		2·41		502 76	Left bank of river.
		8 40		828			4·10	498 66	Highest flood mark, left bank
		11.90					3·50	495·16	Level of water, Jany. 1st, 1868.
		8.50		1,006	—	3·40		498 56	Highest flood marks, right bank.
3	7.03		2 65	1,064		5·85		504 41	Right bank, cross-section No. 1.
		2·50		1,200		4 53		508·94	Small irrigation channel
			3 42	1,400			0 92	508 02	
	18·30		10 28						
	10·28								
	8·02								Check on arithmetical work.

Both of these forms are good, though the latter is more generally useful.

The following form of levelling book is now frequently used by English surveyors, and was apparently first introduced by the American Engineers. The specimen given below comprises the same information as shown in the specimen above :—

Station.	Distance.	Staff reading.	Height of instrument.	Reduced levels.	Remarks .56
1	0	4·56	504·36	500·00	Reduced level of starting point.
		5·34		499·22	Bench mark No. 1 (G. T. S.)
2	500	4 21		500·35	
		6·71	507·06		
	800	4·30		502 76	Left bank of river.
	828	8·40		498·66	Highest flood mark, left bank.
		11·90		495·16	Level of water, 1st January, 1868.
	1,006	8 50		498 56	Highest flood mark, right bank.
3	1,064	2 65		504·41	Right bank, cross-section No. 1.
		7·03	511·44		
	1,200	2·50		508·94	Small irrigation channel.
	1,400	3·42		508·02	

In this form it will be noticed that a staff readings are entered in one column ; to get the height of the instrument it is only necessary to add the "back reading" to the last reduced level, and then the reduced levels of the several stations are obtained directly by subtracting each staff reading from the last entry in column "height of instrument."

The objection to the American form given is that there is no check of the arithmetical accuracy of the work, such as that obtained in the older form by adding up "back" and "forward" columns, and seeing that the difference of their sums agrees with the total rise or fall in the page as shown by the "reduced level." A specimen page of field book is given for the "rise" and "fall" method but the pattern now adopted at the Roorkee College is given below, filled in to show the working, with a copy of the general directions which are printed with each book :—

NOTES.

1. Commence at the top line of the 2nd page, entering the starting B. M. with its reduced level opposite it.

2. Always start with the true reduced level, *i.e.*, the height of the B. M. above mean sea level at Karachi. If you use an assumed datum your levels will be useless as a record.

3. Bench-marks should be carefully sketched and described, not marked: when read the level should *always* be midway between the B. M. and the reference peg. It is advisable, as a general rule, to divert the main line to the B. M. and then back to the original alignment so as to record the exact position as well as the level of the B. M.

4. Intermediates of minor importance in cross section work may be read from the instrument station at uneven distances, and should be recorded with reference to the reading on a line peg as shown in the example.

5. When pegs are situated on local depressions the circumstances should be noted, and if necessary intermediates read to show the level of the natural ground surface.

6. Always end the day's work on a B.M., or a large square peg firmly driven in a situation easily described and found.

7. Never finally record a line of unchecked levels, however short or unimportant; note the check on the record. Long lines, where reliable B. Ms. are not available, can be checked by running two simultaneous lines of levels on the same pegs, the instrument being twice set up and a double set of staff men employed.

8. It is good practice to make an arithmetical check on the work of each page in the field. All pages should be headed, dated and signed. At the close of each day's work the *Reduced Levels* should be inked in, and the levels and survey plotted. The recording in the field *must* be done in ink or indelible pencil.

9. Place the instrument always midway between the staves or at the apex of an isosceles triangle. Intermediates to fix the reduced level of a new permanent mark should only be resorted to if the instrument is in perfect adjustment.

10. If mistakes are made in the record they should be neatly crossed out and the correct figures entered above, initialled and dated. A knife or rubber should *never* be used for erasure or one figure corrected into another.

11. Each field-book must be paged, and a complete index of the work with cross references, where necessary, made out at the commencement of the book.

12. The "Collimation" or "Height of Instrument" method of levelling is as follows:—The back reading is added to height of B. M. on peg at the place, which gives the height of the collimation line at the instrument. All fore readings are subtracted from this value, as also intermediates, and thus all such readings appear on the same line as the reduced levels for the same.

This method is almost universally adopted in England and the Colonies and for engineering practice has certain advantages over the "rise and fall" method.

Check Levelling from B. M. on T. J. P. No. 2.

Station No.	Distance, (feet).		Bearings, (Degrees). Back.	Fore.	Readings. Back.	Int.	Fore.	Height of Instrument.
0	320		260		4·46			884·70
1	280	321	261	80	5·21		2·27	887·64
2	268	282	260	80	2·97		3·06	887·55
3	250	265	290	81	4·62		4·33	887·84
		305		60		3·22		
4	315	251	291	110	3 86		5·77	885·93
5	202	316	202	110	6·23		2 11	890·05
6		201		22			7 02	
				Check	27·35		24 56	
					24·56			
					+ 2·79			

to T. J. P. No. 4. Dated..............................Page.........

Reduced level.	REMARKS.
880·24	On top T. J. P. No. 2 villages Bikrampur, Tajupur and Mandlana.
882·43	
884 58	
883·22	
884·62	On top T. J. P. No. 3, villages Tajupur, Sikri and Mandlana.
882·07	
880·82	
883·03	On top T. J. P. No. 4, villages Sikri, Bela and Chakdara
+ 2·79	

Longitudinal Section continued.

Station No.	Distance, (feet).	Bearings, (Degrees). Back.	Fore.	Readings. Back.	Int.	Fore.	Height of Instrument.
23 + 75		272		4·68			887·71
	24 + 00				2·2		
	25				4·6		
	50				3·3		
	75				6·7		
	25 + 00				5·4		
	25				6·2		
	50				5·2		
	75				6·3		
	26 + 00				4·7		
	+ 25				1·8		
	+ 50				2·4		
	+ 75				3·6		
	27 + 00				2·2		
27 + 25			92	3·27		3·43	887·55
	+ 50				1·6		
	+ 75				1·8		
	28 + 00				3·2		
	etc.				etc.		

Note.—This section has been taken at shorter distances than 100′ for a special purpose.

Dated...Page.........

Reduced level.	Remarks.
883·03	On T. J. P. No. 3. (top).
885·5	
883 1	
884·4	
881·0	
882·3	
881·5	
882·5	Measured to eyepiece of instrument = 5·2.
881 4	
883·0	
885·9	
885·3	
884·1	
885·5	
884·28	
886·0	
885·8	
884 3	
etc.	

Cross section taken at Chainage 25 + 50.

Station No.	Distance, (feet).	Bearings, (Degrees). Back.	Fore.	Readings. Back.	Int.	Fore.	Height of Instrument.
23 + 75		272		4·68			887·71
	8		351		2 6		
	11				7·0		
	17				4·3		
	21				5 8		
	33				7 2		
	36				3·6		
	0				5·2		
	12		171		4·7		
	16				6·4		
	20				9·7		
	25				8·6		
	32				8·4		
	40				7·3		
27 + 25			81			3·48	

Note.—This cross section has been taken at close intervals as a special case

Dated...Page.........

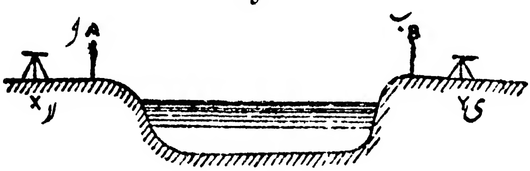
Reduced level.	REMARKS.
883 03	
885·1	
880·7	
883·4	
881·9	
880·5	
884·1	
882·5	Measured to eyepiece of instrument = 5 2.
883 0	
881·3	
878·0	
879·1	
879·3	
880·4	
884·28	

104. Flying Levels.—These are run for approximate values only: longer distances intervene between instrument and staff and often readings only to the first place of decimals are made. Thus the work is rapid and hence the nomenclature.

105. Reciprocal Levelling.—Sometimes a wide river, marsh or other impediment has to be crossed and a detour is not feasible. The method of reciprocal levelling must be adopted to obtain correct values and for the elimination of curvature. When there is one instrument* and the accuracy of precise levelling is unnecessary the following is the method of transferring an elevation across a barrier of the nature above mentioned.

Set up the instrument at X say 30 feet from the staff A and so that XAB is a straight line; read the staff at A and at B. Let the reading A be 5·09 and B 6·94 and on the reduced level of A 1,000 feet. This gives 1·85 as one difference. With the instrument at Y 30 feet from B and ABY in a line let the readings on B and A be 4·69 and 2·88 respectively. This gives a difference of 1·81. The mean of the two differences is 1·83, which is the correct difference of level and thus the reduced level of B is 1000—1·83 = 998·17 feet.

Fig. 49.



The instrument at X and Y may be raised or lowered and re-levelled to get another set of readings; the more sets of readings the greater the accuracy of the mean. It must be noted in the above that although curvature and error in instrument is eliminated refraction may not be, and it is for this reason that in precise work two instruments are used and readings are taken simultaneously and so that the instrumental errors † are cancelled; the instruments are also interchanged.

One instrument‡ is set up at X and the other at Y and the rods A and B will be placed to the front and to one side of X and Y so as to give clear sights. At a given signal X reads B and Y reads A, then X reads A and B reads Y and this may be continued and a number of sets taken. Then X and Y interchange and the same procedure is carried out. The mean difference by each observer and the mean of these differences is the true difference of level of the two staves.

* With a single Kern level with five results a mean probable error of ± 0·5 millimetre was obtained for a river ½ mile wide.

† There is no guarantee that there is no instrumental error because instruments are usually adjusted over a distance of 300 to 400 feet as maximum, so that if the river is much wider than this it is quite possible that there still remains a small error.

‡ The instruments should be preferably of the same power of telescope and value of bubble tube.

106. Field work.—The following applies to the older patterns of Levels. Set up the stand or tripod midway between two staves so that two of the legs are in a direction at right angles to the line between the staves, that is with one leg pointing either to the foresight or backsight. Take the instrument out of its box very carefully and note before doing so the position in which it sits in the box, and, if necessary, make notes along the edges of the box so that it will invariably be replaced in the correct way. Set the instrument on the stand, screw it on, or clamp it in the slots of the tribach and examine it and the stand for any shake and remedy it before commencing work. With the eye focussing screw and with a piece of white paper in front of the object lens eliminate parallax first with the eyepiece obtaining a sharp and clear view of the wires and then focussing the object glass on to the staff and noting that the wires do not move, that is that the image formed by the object glass is brought into the same plane as the wires. Adjust till perfect (*see* para. 56).

(1) Place one hand lightly on the telescope and one hand on the leg of stand (pressed against the thigh) which points up and down the line. By means of this leg and a lateral motion to and fro bring the bubble approximately to the centre of its run the telescope being at right angles to the line. Now bring the telescope into the line between the staves and with the leg still held in the hand raise it or lower it so that the bubble is brought into the centre approximately. Repeat if necessary. The object of pressing the leg of the stand against the thigh is to avoid jerks and snaps. These two movements should not take more than 10 seconds to do. The legs are now pressed well home and one or two turns of the footscrews should be sufficient to start the bubble moving.

(2) Turn the telescope in a direction at right angles to the line of sight when it will be over two footscrews. Twist these footscrews both equally inwards or both outwards and bring the bubble to the centre of its run. Now turn the telescope at right angles to its present direction when it will be in a line pointing to either the back or forward flag and bring the bubble to the centre of its run by the remaining footscrews if a four screw instrument, and by the other footscrew if a three screw instrument. Return to the first position, correct any deviation in the bubble and again return to the second position, pointing preferably to the back flag. If the instrument is in adjustment then the bubble will remain in

the centre of its run in any position of the telescope on its horizontal axis, though it will be shown later that such a condition is unnecessary.

(3). Set up the staff on the back station focussing having already been done for eliminating parallax, note the reading and enter it, first the whole number of feet then the decimal part of the foot and without altering the "stance" of the feet repeat and check reading, also bubble, keeping the body and head directly behind the instrument and in an easy and comfortable position. This completes the work on the back staff. Usually as only one staff is used the observer must wait till the staff man reaches the forward position, and during the interval the observer should see that his instrument is not handled and that he does not unnecessarily walk around it, which might lead to the instrument, in unstable ground, settling down on its legs.

(4). When the staff man has reached his forward position turn the telescope on him and examine the bubble and bring it to the centre of its run, if necessary. There will be no need to refocus as the distances are equal, at any rate refocussing should be avoided as any error in the focus slide or draw tube will creep into the observations. Read and enter recheck, etc.

(5). If compass bearings are to be taken the compass needle should not be unclamped till the instrument is level as it may lead to unequal wearing of the pivot. The compass reading is taken after the staff reading in each case and before the instrument is moved and carried the needle is again clamped.

(6). The measuring with the chain would take place as ordinarily on survey work. If stadia wires are read for distances then the distance of the back being read between the two outer wires the forward man is moved closer in or further away to get the distance of the foresight equal to the back. If the level wire is exactly equidistant between the stadia and wires then the mean of the stadia readings should be equal to the readings of the level wire or the central wire, which is a useful check. If there is a slight error this will be a constant, which might be calculated, if required.

From a practical point of view there is no necessity to try and get the bubble to read exactly in the centre of its run for every position of the telescope. Provided that the instrument is midway between the staves and the bubble is in the middle of its run at the instant of observing and the cross-direction of the bubble is very nearly correct there will be no error in the difference of level between the two staves. In other words

the following movements of the telescope over footscrews should be sufficient if the levelling by the legs has been properly done :—

(A) That over two footscrews or at right angles to direction of line.

(B) That over one footscrew or parallel to direction of line pointing to the back staff.

(C) In an end to end position to read forward staff.

The following is the order in which observations should be made and the other precautions to be taken which might be termed instrument drill, the instrument being a three footscrew pattern :—

(*a*) Set up and clamp level on stand.

(*b*) Focus on to the staff and eliminate parallax.

(*c*) Roughly level by one leg of stand and press home legs.

(*d*) Place telescope in position A (*supra*) and level by footscrews.

(*e*) Place telescope in position B (*supra*) and level by third footscrew.

(*f*) Unclamp compass needle.

(*g*) Read and enter staff reading.

(*h*) Check staff reading, the entry and the bubble.

(*i*) Read and enter back bearing.

(*j*) Signal to staff man to move to forward position.

(*k*) Start chainmen chaining.

(*l*) Place telescope in end to end position, (*supra*) correct bubble, if necessary by third footscrew.

(*m*) Read and enter forward staff reading.

(*n*) Check staff reading, the entry and bubble.

(*o*) Read and enter forward bearing.

(*p*) Clamp compass needle.

(*q*) Bring footscrews to the centre of their run and clamp instrument axis.

(*r*) Ink up record of chaining and offsets, etc.

(*f*) (*k*) and (*r*) it is possible are dispensed with in some levelling such as check and flying levelling. If stadia readings are being taken they will come after steps (*h*) and (*n*).

107. Stadia and Levelling.—The following system will be found to ensure accuracy in results when levelling is combined with stadia readings for distances. As there is no reason why the instrument should not be in perfect adjustment as to its line of collimation and which line can be adjusted in a very short time, and for quick work, that is, ascending and descending slopes where distances cannot be made equal between the

instrument and staves without sacrificing a great deal of time, it may be taken for granted that any inequality in the distances between the instrument and staves will produce from this source no error in results.

Therefore having set up the instrument with one footscrew pointing up or down the line roughly level by the legs, and bring the bubble to its centre by footscrews (*vide* para. 106), and the following order may then be observed :—

(1). Read and enter value of level reading on the staff.

(2). Depress or elevate telescope by means of the footscrew over which it is resting so that a stadia wire reads an even foot, the intercept is thus easily calculated and the distance entered in the book.

(3). Look through the telescope and bring the central wire on to the reading already entered as the level reading by elevating or depressing the footscrew as before. The bubble should return to the centre and is at once a check on the work.

Over flat and fairly even ground a fairly central position for the instrument can be obtained by pacing.

108. Errors in levelling are due to the following causes :—

(1) Imperfectly eliminated parallax, one of the chief causes.

(2) Unequal distances between instrument and staves.

(3) Unstable ground for both instrument and staff.

(4) Non-verticality of the staff, another of the chief causes.

(5) Bad focussing and changing focus.

(6) Bubble leaving the centre owing to the shifting of the feet or "stance" in the interval between the adjustment of bubble and the actual taking of the reading.

(7) Heat and wind causing the staff image to vibrate, light and shade variations.

(8) Length of sights being beyond the power of the telescope and sensitiveness of the bubble.

109. Mistakes in levelling are due to the following causes :—

(1) Recording the wrong feet or decimals, usually feet.

(2) Reading to a staff held upside down.

(3) Reading the forward staff without checking the bubble.

(4) Taking one of the stadia wires as the level wires.

110. Prevention of Errors—1. Parallax should be eliminated by placing a piece of white paper in front of the object glass (the slide of

the object glass being home and not extended) and then by moving the eyepiece in or out obtaining a clear distinct and defined image of the cross-wires. This temporary adjustment should not alter for the same observer and hence a screwing eyepiece is suggested instead of the plain cylindrical surface to be pushed in and out and which in time works loose in the slot and is always thus requiring readjusting.

Now with the object glass focus on the staff and if the graduations of the staff appear to move up and down when the eye is moved, then parallax is not eliminated and the image formed by the object glass is not in the same plane as the wires. Correct again with eyepiece and refocus.* Imperfectly eliminated parallax will sometimes give an erroneous reading of several hundredths.

2. So long as the distances between instrument and staves are equal and of moderate length (not over 300 feet except in flying levels) and the bubble is brought to the centre of its run for each observation all errors are cancelled, also error in the focussing slide, if any. As instruments can be so easily adjusted (*see* para. 79) and with care kept in order there is no reason why the medial position should be faithfully adhered to, in fact when "intermediates" are taken it is sometimes impossible to be midway.

3. The settling down of an instrument between the observations of the back and forward staff means that the backsight is lessened and the calculated elevation of the foresight will be too high, or in other words if the instrument had sunk one inch, one inch less would be read on the foresight and hence the reduced level of the forward staff would be one inch higher. The settling down of the instrument has therefore a tendency to cumulative error. This can be avoided by selecting the ground, pressing home the legs and taking a foresight as soon after the backsight as possible.

The settling of the staff between two stations will tend to make the elevations higher, that is the error is again cumulative because the backsight from the next station will give a higher reading and hence the instrument will be higher, and so on. This can be avoided by the selection of good ground for the staff and also by the surveyor himself turning the rod carefully as he passes by to his next station. Errors, due to settlement of

*The reader should understand that there are two temporary adjustments which must be made to eliminate parallax, and that although the clear image of the wires may be obtained with the eyepiece, yet owing to the focus of the object glass being changed for different distances parallax will have to be eliminated at every change of focus.

instrument and staff, are eliminated by levelling back in the opposite direction. As these errors are both cumulative it must be that the flatter the gradient obtained in levelling, the more accurate the work.

4. Non-verticality of the staff is the commonest source of error, especially in India where the staff men are uneducated and have no interest in the accuracy of the work. If the staff leans towards the observer or away from him the readings are greater than if the staff were upright. If the lean were equal for foresight and backsight the error would be compensating, but such cannot as a rule be the case. In levelling uphill the foresight would be observed near the base of the staff, hence the error for verticality would be little or nothing, but the backsight being lower than the observer the staff would be observed high up and the error for verticality possibly great. These errors would be compensating if the leveller returned down the hill and closed on his starting peg, and though the closing error might be *nil*, yet the height of the hill would be much higher than it really is. Errors of non-verticality can be avoided by using a suspended mason's plumbbob, or by waving the staff and observing the lowest reading, that is when it is upright. If the waving to and fro method is adopted the ground beneath the rod should be hard to prevent a gradual settlement and the staff man should see that no mud or dirt is taken up on the base of the staff. Any stereotyped method of holding the staff between the toes or balls of the feet with the thumbs brought up to the level of the mouth the staff to touch the nose, etc., will tend to cancel errors of non-verticality, because provided the ground is flat for the feet at any station the same angle of lean will always be observed. Another method is for the staff man to stand on one side of the staff and attend to its verticality in one direction and for the leveller to correct him for the other. The use of the plummet is perhaps the best.

5. Bad focussing leads to indistinct readings and on the forward staff being observed and the focus corrected any error in the slide of the draw tube will produce an error in reading. As the distance between instrument and staves are equal any imperfect focussing of the back station should remain for the forward station if there is any suspicion of bad fitting in the draw tube,

6. It is necessary that the bubble be in the centre of its run at the instant of reading. The reason for this has been already explained. To bring the bubble to the centre of its run and to be sure of its remaining thus till the observation is read, is best achieved by preventing any shift

in the weight of the body. This can be arranged for by setting up the level so that the bubble tube is about the level of the eye and it can be seen by leaning to one side without shifting the feet. On large and precise levels reflectors are fitted to prevent this change of "stance" and the prism levels render a change unnecessary. The binocular level permits of the bubble and the staff being read at one and the same instant.

7. When the staff graduations are beginning to lose their distinctness and the staff becomes wavy owing to heated atmosphere it is advisable to stop work or to work with shorter intervals between staves. If, in a high wind, the instrument and staff vibrate, work should be suspended. Refraction is practically constant between the hours of 11 A.M. and 3 P.M. and is greatest in the early mornings and late evenings. A decided variation takes place when the instrument and staff are alternately passing from light to shade and under such circumstances the observer should take readings between staves either when they are both in the sunlight or both in the shade.

8. Length of sight is controlled mainly by the magnifying power of the lenses, condition of atmosphere and sensitiveness of the bubble tube. The staff should not be so far away so that the 100th part of a foot is not clearly distinguishable.

The ordinary engineer's level is usually fitted with a 20 second bubble, and when the bubble is not very sensitive it stands to reason the error in readings over long shots such as 400 to 600 feet is very marked and that great accuracy is not possible. If a man is quick with his instrument the question of long shots to cover ground should not be considered. An average distance of 500 feet between staves will be found to be a good maximum working interval.

In precise levelling the distance should never exceed 600 feet between staves. The following information is worthy of notice. With the binocular level a coast survey observer in regular work has occupied 120 stations in less than eight hours, the average time per station being 4·6 minutes, including setting up and dismounting the instrument and then walking from station to station. With the average length of sights of 200 feet (400 feet between staves) as much as 200 miles of precise levelling has been done in a month. Such speed would not be possible except under perfect weather conditions.

111. Value of bubble tube divisions.—In the previous paragraph the value of the bubble has been commented upon and as it

is necessary that this should be sometimes known, the following method for ascertaining the value of one division of the bubble tube is given.

If x equals the number of divisions of a bubble through which a subtended interval S in feet has been read on the staff, (d) being the distance in feet of staff from the instrument, then each division of the bubble equals $\left(\frac{S}{xd \times \sin 1''}\right)''$ since sin 1″ = circular measure of 1″.

Example.—With a Y level on a level staff 200 feet distant it was found that while the bubble moved over 25 divisions of the bubble tube the reading on the staff altered from 6·75 to 6·375 or the subtended interval on the staff was ·375 feet.

Find the value of one division of the bubble.

$$\text{By formula one division} = \frac{S}{x \times d \times \sin 1''}$$

$$= \frac{\cdot 375}{25 \times 200 \times \sin 1''}$$

$\therefore$ log one division $= 1{\cdot}5740 - 1{\cdot}3979 - 2{\cdot}3010 - 4{\cdot}6855 + 10 = 1{\cdot}1896$

$\therefore$ one division $= 15{\cdot}5$ seconds.

Or again :—to reduce to seconds, radius here being 200 feet.

$$\text{Circular measure for } 1'' \times r = \frac{\pi r}{180 \times 60 \times 60} = \frac{3{\cdot}14159 \times 200}{180 \times 60 \times 60} = \frac{3{\cdot}14159}{3240}$$

$= \cdot 001$ very nearly.

$\therefore$ 1 second subtends on the staff 001 feet (very nearly.)

$\therefore$ 375 seconds will subtend ·375 at 200 feet but bubble moved through 25 divisions and therefore each division of the bubble is equal to $\frac{375''}{25} = 15''$.

112. Care of instrument, staves and final cautions.

(1) Note the position in which the instrument lies its box and take it out gently lifting it by its lower frame work not by the telescope.

(2) Place the instrument on the stand clamp or screw it firmly on its stand and shield it from the sun as much as possible. Examine instrument and stand for shake.

(3) Avoid jars in the preliminary levelling by the legs of the stand.

(4) Do not unclamp the prismatic compass needle till the instrument is levelled and then clamp it before carrying or putting the instrument away.

(5) Always bring the footscrews to the centre of their run when work at a station is completed.

(6) If the instrument has a clamp and slow motion screw, the instrument should be clamped before is it carried or put away to prevent unequal swinging of the axis on the pivot and thus unequal wear.

(7) Do not set up instrument on a smooth floor or pavement without caution as the legs may spread-eagle and let the instrument down. Be careful how you carry an instrument through an open door or under trees.

(8) Do not meddle with the lenses or clean them with silk or muslin, wash leather is best. If the object glass is to be removed then its position as placed by the maker must be scratched on the edge of its ring so that it can be returned to its exact position. First class instrument makers usually etch a line for guidance.

(9) In adjusting the bubble or diaphragm do not tighten one screw before loosening the opposite one.

(10) Do not force screws. If footscrews jamb they either require attending to as regards tension screws, or may work easily in a different set of slot holes. If footscrews are hard to move then they are either very much out of the centre of their run or the slots in the stand have been damaged so that the distance between slot holes do not agree with the distance between the footscrews. Some makers dot the footscrew and the particular slot of the stand in which that footscrew should be placed. However the jambing of footscrews is a fruitful cause of bad levelling, and as it is mostly due to the slots of the stand the "screw on instrument" is a much better arrangement and this has been advised under "choice of instrument." The footscrews should move true axially that is, if the telescope is placed over one footscrew, the instrument being more or less level, on the footscrew being turned the image in the telescope should move vertically up and down and not sideways as well. The effect of this error is not noticeable in levelling but is very marked in angular work with the theodolite.

(11) The instrument should be replaced in its box very carefully and in a dry condition, the lid of the box being brought quietly down without jar or forcing and the clamp screw tightened. If the box is to be carried over a journey then packing should be well wedged in to prevent the instrument being shaken. If the instrument is to be put by for any lengthy period in places where dust accumulates such as in India, paper should be pasted over all cracks.

(12) The staff man should never be permitted to approach too near the instrument while carrying the staff.

(13) If there is no sunshade to the object glass make a temporary one out of paper and a pin. Avoid casting a shadow on it with your hat or umbrella unless you can make sure that the whole of the object glass is shaded.

(14) Keep still when observing and take up an unstrained attitude with the hands off the instrument.

(15) Do not tire the staff man by keeping him on the "qui vive" when it is not absolutely necessary.

(16) Staves should be hung up or laid face to face on the ground. They should not be leant against walls or trees and should be put away dry and freed from mud and sand.

(17) Attend to parallax, stability of ground for instrument and staff, verticality of staff, the bubble in the middle of its run at the instant of reading the staff, the instrument midway between staves, the reading of the feet first and the decimals next, remembering that if you "make sure of the feet the decimals will follow" and see to their correct entry in ink.

(18) Erasures are never permitted except in ink when the wrong entry should be neatly crossed out and the correct one entered above, initialled and dated. Pencil entry is never allowed in any original record.

The fulfilment of these precautions will produce the best of results whether the instrument is in adjustment or not. Finally use the instrument so as to obtain good results and not as if you expected it to give them.

For ordinary check levelling if the chain is used a squad of 5 men is necessary, without the chain, 3 men. Modern levels fitted with stadia do not need chainmen.

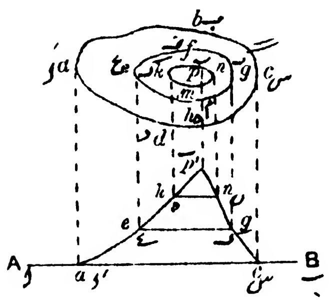
113. Contouring.—Contouring means tracing on the surface of the ground horizontal lines with a fixed vertical height between adjacent lines; the vertical height will vary with the nature of the country contoured and the object for which the contour survey is required, and is fixed accordingly. The positions of these horizontal lines are surveyed and protracted upon a map, in the same way as any other boundary lines.

Contour lines are either traced round isolated features of ground for designing plans for drainage, buildings or other engineering purposes, when the correct features and levels of the country are required to be seen at a glance, or over a whole tract of country, with a view to giving a

mathematical representation of the surface of the ground in connection with a national, or other extensive and accurate survey.

Let the following plan (*Fig.* 50) represent the contoured top of a hill, the figure below an elevation, parallel to the line AB. Then each of the lines in plan would be seen in elevation as follows :—

Fig. 50.



abcd as *ac* ; *efgh* as *eg* ; *kmn* as *kn* ; and the top as *p* ; the vertical heights between *a* and *e*, *e* and *k*, being all equal, say, 1, 5, 10, or more feet apart as circumstances require. It will be seen that the steeper the hill is, the nearer the contour lines approach steep hills, the scale or else the vertical distance between each line must be made large to give room for the lines to be clearly drawn on the plan, for it is simply useless to survey lines which cannot be plotted ; and, on the other hand, in districts which are nearly level, contours having a great vertical distance between them would be of little practical utility. When contour lines run for long distances and close together, it is a great help, for ready inspection of the plan, to make every fifth line or so either thicker or of a different color.

In contouring a hilly country, the watershed of the spurs will always be found to have the most gradual and even slope. It is the best plan, therefore, to run a line of levels down each, fixing pegs at the point where each contour line crosses it, pegs on the same contour being similarly numbered : to do this the levels down each spur must have been properly connected, and this is conveniently done by running an auxiliary line of levels from a point in the line down one spur to some point similarly placed on the next spur. The reduced levels down each spur having been thus connected, the contour pegs (say 5 feet apart) down each spur can now be fixed. The instrument is then put up over each peg in succession, and, its height having been taken by a levelling staff with a vane affixed a man with the vane is sent to any point between the two spurs which it is wished to fix, and he moves the vane staff up or down the hill side till the cross wires of the level cut it ; this point is then fixed and its bearing read off: in the same way any required number of other points in that contour is determined. From the corresponding contour peg on the other ridge, the bearings of these points are again read with a prismatic compass, and plotted on the map with reference to the pegs on the ridge by means of

the cross bearings the position of which pegs must be accurately fixed by a survey. The positions of the pegs may also be fixed by running traverses with the theodolite between known points along the line of each contour, and taking an off-set to each peg in succession; when the country is moderately level this is much the most convenient plan to adopt. If there is no instrument for reading the vertical angles, the horizontal distance of the line of pegs on the watersheds may be fixed as follows: Let $r =$ the measured distance between two consecutive pegs on the watershed, $h =$ the difference of level, then $\sqrt{r^2 - h^2} =$ the horizontal distance between these two pegs; it will be seen that these watershed pegs should be made to run in as straight lines as possible to facilitate the survey of them.

The reflecting hand-level, or the contouring glass with a prismatic compass, is also well adapted for filling in the points between the watersheds.

114. Contouring large areas.—The above method is for very distinctly marked ground and of small area, but for canal irrigation and drainage works in ordinary country, the slopes are not perceptible to the eye at all clearly, if at all, yet a perfect contour map may be made with no difficulty. Lines of levels must be taken running parallel or nearly so to each other and at any convenient distances apart, the distances varying with the nature of the country and the object of the survey. The stadia for reading distances will be found a great time saver. After plotting the reduced levels on the plan of the field work, contour lines may then be drawn on the plan by interpolation joining the points of equal elevation and at any convenient height apart. If the drainage lines of the country have also been traversed and plotted, a fairly approximate series of contours may be traced. Should greater accuracy then be required, these lines may be levelled, the bearings of the lines being taken from the plan, and any requisite alterations made; but as a rule in the plains of India, the plan of a tract of country contoured in the above manner is sufficiently accurate to determine either the main line of a large canal, or the direction of any of its distributing channels.

For less accurate work, such as is required in military sketching, in making a preliminary investigation for a hill road or in running in intermediate contours, either a protractor with a string and weight attached, or a reflecting hand-level, will suffice. Such instruments are easily used, and being adapted to the size of one's pocket are very handy.

In connection with contouring that portion of the chapter on engineering surveys which treats of canal surveys should also be read.

115. Boning Rods.—For the purpose of laying down a pipe line or a given gradient between level pegs boning rods are used. These are made of wood, T shaped, and usually 3 are used as follows. Two are placed on the pegs and the third one at any intermediate point and as they are made of the same height it stands to reason that if the intermediate one is sighted to be on a level of the other two it is in the correct grade line. This is done by the workman kneeling behind one sighting the further to get a coincidence of the tops of the T or rods and setting the other to coincide and so on.

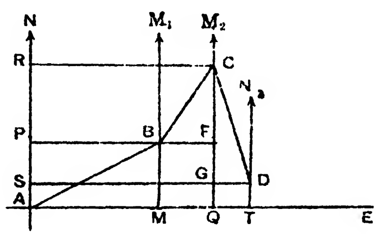
CHAPTER V.

TRAVERSING AND ITS COMPUTATIONS AND CITY SURVEYING.

116. Definition.—A Traverse may be defined as a circuitous route performed on leaving any place on the earth's surface, by stages of straight lines, in different directions, and of various lengths, with a view to arriving at any other place situated in any direction with reference to the former, and at any distance therefrom which cannot be reached in the direction of the shortest line connecting them.

Let AB, BC, CD, (*Fig.* 51) be the first three lines of a traverse, and NA the meridian, which may be either the true or the magnetic meridian, or even some direction making a giving angle with some well defined object observed at the starting point. The bearing NAB was first observed, then AB measured, then the angle * ABC read, then BC measured, then BCD read, then CD measured and so on.

Fig. 51.



By the ordinary method of plotting AB would first have to be protracted, its distance laid off, and thus the point B is found ; similarly from the point B, BC is protracted, and its distance laid off, the point D in a similar manner is arrived at, and so on.

Now, if any error arises in the *protraction* of the angles NAB, ABC, BCD, etc., that error is carried on throughout. To obviate this repetition of error the method of co-ordinates has been resorted to.

Draw AE at right angles to the meridian NA ; also the lines N_1BM, N_2CQ, N_3DT parallel to NA, and CR, FBP, DGS, parallel to AE. Now if the distances AM and MB are known, by setting off AM along AE and MB at right angles to AE the point B is at once found. Similarly with the points C and D, and so on. But the laying off of the co-ordinates AQ, QC of the point C is quite independent of those of the point B, as can be thus shown :—

The bearing of AB = the angle NAB = angle ABM.

* All angular instruments read angles according to the rotation of the hands of a clock.

Now $AM = AB \sin ABM$, and $MB = AB \cos ABM$: consequently the co-ordinates of B, AM and MB are easily found.

N_1BC is the bearing of BC = angle BCF. In a similar manner BF and FC are found.

From the construction of the figure it will be seen that the co-ordinate AQ of the point $C = AM + MQ = AM + BF$, both of which are known similarly $CQ, = CF + FQ = CF + BM$; therefore the co-ordinates of C are known, and therefore the point C can be laid down on paper perfectly independently of the point B. Similarly for D : $AT = AQ + QT = AQ + GD$, and $DT = GQ = CQ - CG$; and so on.

117. Gale's Traverse System.—Gale's Traverse System is a method of protracting by rectangular co-ordinates, and is applicable to any mode of surveying whatever, such as Route Surveys, Railway Lines, Navigation Courses, and the like, where every station is fixed by the distances on the meridian and perpendicular. The distances BM, CQ, DT, etc., or in other words, their equals AP, AR, AS are known in Gale's Traverse System as *latitudes*, *i.e.*, the distances North or South (in this case all North) of the point A on the meridian AN ; and the distances AM, AQ, AT, as *departures*, or longitudes, *i.e.*, distances from A along AE East or West of A (in this case all East).

118. Conditions when a Traverse closes.—When a traverse makes a complete circuit, *i.e.*, returns to the starting point, there are three different *conditions* that must be fulfilled :—

1st.—That all the interior angles, together with four right angles, must be equal to twice as many right angles as the figure has sides. This is a little apt to mislead. *All* the angles must be *observed* ones and on returning to the starting point the interior angle between the last and first line of traverse must be *observed.*

2nd.—That the "Northings," or distance travelled North, must be equal to the "Southings," or distance returned South.

3rd.—That the "Eastings," or distance travelled East, must be equal to the "Westings," or distance returned West.

The first condition is proved in Euc. I., 32, Cor. I, and a very little common-sense will at once perceive the correctness of the second and third conditions.

119. Method of Computing Bearings when working by Inward angles.—Let ABCDEFGHIJA (*Fig* 52) represent a ten-sided polygon, which has to be surveyed and let NAS be the magnetic meridian

through A. Set up the theodolite at A, and observe the angle NAB ; this angle is a magnetic *bearing* of AB to the meridian. Then set up the instrument in succession at B, C, etc., and proceeding *anti-clockwise* observe all the interior angles ABC, BCD, etc., and finally set the instrument again at A, and observe the inward angle JAB. In this case, as it is a ten-sided figure, the sum of the included angles must equal 1440°, *i.e.*, (180° × 10 -- 360°) = 1440°.

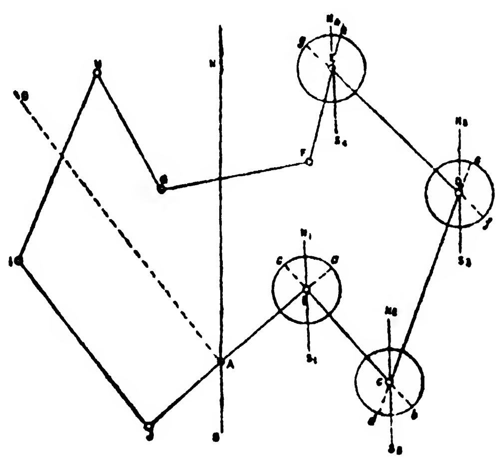
In practice it will be found that this result cannot be exactly attained, and that the sum of the angles will generally amount to two or three minutes more or less ; to meet this, a correction of one minute in every four or five angles, additive or subtractive as the case may need, is generally necessary to obtain the result required.

The bearings of the various sides are found by means of the following rule :—

To the bearing of the line preceding that of which the bearing is sought add the inward angle formed by these two lines, and the sum increased or diminished by 180° according as it may be less than, or in excess of, 180°, will be the bearing of the next line.

Let the bearing of the line AB in the figure be given.

Fig. 52.



To find the bearing of the line BC.—Produce AB to *a*, and CB to c. The two meridians NS and N_1S_1 being parallel, the angle ABS_1 is equal to the angle NAB ; if to the angle ABS_1 the interior angle of polygon

ABC, or its equivalent in arc is added, the angle formed by the line CB with the meridian N_1S_1 or angle S_1BC is obtained ; if then the angle S_1BN_1 or 180° be deducted from this, thus reversing the direction of the line, the angle N_1BC is left, and this is the bearing of the line BC with the Meridian N_1S_1.

To find the bearing of the line CD.—Produce BC to *b*, and DC to *d*. The two meridians N_1S_1 and N_2S_2 being parallel, the angles N_1BC and BCS_2 are equal. If to the angle BCS_2 is added, the interior angle of the polygon BCD, the angle formed by the line DC with the meridian N_2S_2 or angle S_2CD results, if then the angle S_2CN_2 or 180° be deducted from this, thus reversing the direction of the line, the angle N_2CD is left, which is the bearing of the line CD with meridian N_2S_2.

To find the bearing of the line DE.—Produce CD to *e*, and ED to *f*. The two meridians N_2S_2 and N_3S_3 being parallel, the angles N_2CD and N_3De are equal. If to the angle N_3De or arc N_3e, the interior angle of the polygon CDE, or its equivalent in arc *ef*, is added, the angle formed by the line ED with the meridian N_3S_3 or arc N_3ef results ; if then the angle *f*DE or 180° be added to this, thus reversing the direction of the line the angle N_3DE is obtained, which is the bearing of the line DE with the meridian N_3S_3.

To find the bearing of the line EF.—Produce DE to *g*, and EF to *h*. The two meridians N_3S_3 and N_4S_4 being parallel, the angles N_3DE and N_4Eg are equal. If to the angle N_4Eg or arc N_4hS_4g, is added the interior angle of the polygon DEF, or its equivalent in arc gN_4h the angle formed by the line FE with the meridian N_4S_4, or arc $N_4hS_4gN_4h$ results, from which if the angle *h*EF or 180° be deducted, thus reversing the direction of the line, the angle N_4EF is left, which is the bearing of the line EF with the meridian N_4S_4.

And so on, this rule may be carried through every line of the polygon as far as the last line JA, when its bearing, added to the interior angle JAB + or − 180°, as the case may require, will give the original starting bearing of the line AB.

If as will occasionally happen the sum of the preceding bearing and forward angle diminished by 180° amounts to more than 360°, deduct 360° from the total—the remainder will be the bearing of the line. A moment's consideration will show the reason for this, for as the horizon is only divided into 360° parts, and as 0 and 360 represent the same division, it is

evident that as soon as the needle swings past the division 360 the small numbers must begin again.

119A. Corrections for latitude and departure.—The columns of latitude and departure will not be found to balance exactly, for inaccuracies must arise from observations and chaining, in the field, which no care could obviate. On the Revenue Survey, the amount of error allowed is one link in ten chains, additive or subtractive, from the sums of the Northings and Southings to correct the latitude, and from the sums of the Eastings and Westings to correct the departure.

This error must be apportioned among each of the distances of the survey by the following proportions, *viz* :—

As the sum of all the measured distances is to the whole error, so is each distance to its correction (*see* also para. 135) but as this is a somewhat lengthy process it is found sufficient to balance all ordinary traverses by proportioning the error with reference to the total error in latitude or in departure—as in example (Traverse Form A) where ·2 feet departure (cols. 9a and 10a) is to be distributed equally to the two greatest departures plus and minus, instead of going into the second place of decimals which is beyond the limits of accuracy of the chain measures in the field work.

This must be done independently for the latitudes and also for the departures; and is entered in a column appropriated to each, called the North and South correction, and the East and West correction ; the correction, thus determined, must be placed collaterally with the distance to which it refers, without distinguishing as to North, South, East or West.

Having found the several corrections for each of the latitude and departures, add them together severally, and see whether their total agrees with the whole error, and if so, proceed to allot the corrections. If the error be an excess of Northings, subtract each correction from its collateral Northing, or add it to the collateral Southing ; if an excess of Easting add to the Westing and subtract from the Easting ; the sums of the corrected latitudes and departures will then be found exactly to agree.

120. The Traverse Table.—On the next page is given the Traverse Table of an actual survey by inward angles (*see* Form A).

Col. 1 contains the figures representing the stations of the Survey.

Col. 2 contains the inward angles.

Col. 2A contains the corrections to be made in those angles so that the *first condition*, para. 118 may be fulfilled.

Col. 3 contains the bearings of the several lines deduced, as per rule, para. 119.

Col. 4 contains the reduced bearings. *i.e.*. the angle adopted to tables of logarithmic sines and cosines.

Col. 5 contains the distances as measured in the field.

Col. 6 contains the cardinal direction of each line.

Cols. 7 and 8 contain the distance on the meridian between every two stations.

Cols. 9 and 10 contain the departure of each station from the meridian of the preceding one.

Cols. a, a, a, a contain the corrections necessary so that the *second* and *third conditions*, para. 119A, may be fulfilled.

Col. 11 contains the distances on the meridian of each station from the origin The letters N. and S. showing whether the several stations are situated North or South of the origin.

Col. 12 contains the departure of each station from the first in the series, the letters E and W. showing whether the several stations are East or West of the origin.

Col. 13 contains the successive ordinates of departures.

Cols. 14 and 15 contain the values for double areas.

Col. 16 column for remarks. In triangulation when stations are set up as a traverse and heights of station are known, also in traversing when the traverse pegs have been levelled to, this column can be also utilised for the record of such heights.

Columns 1, 2, *and* 5 are taken from the field book.

Column 2.—The sum of the angles in col. 2 is too much by 40 secs. Since the theodolite issued is supposed to be one graduated to read 20″ then 40 secs. should be subtracted in two sums of 20″ each. The error has been applied in the correction col. 2A to equidistant stations E and I but it would be really more correct to apply the correction to the angle between the two shortest lines or at stations F and E.

Column 3.—The bearing of the first line AB that is A to B was observed to be 199° 48′ 00″. This value is placed opposite B in col. 3. The bearings of the other lines are found according to the rule given and to take a concrete example are as follows :—

Example.—Bearing of the line E to F or EF = 75° 51′ 00″ + 182° 32′ 00″ − 180°′ 0′ 0″ = 78° 23′ 00″. Bearing of the line H to I or HI = 82° 50′ 30″ + 49° 50′ 00″ + 180° 0′ 0″ = 312° 40′ 30″.

Note the check at station A for closing bearing = 199° ·48′ ·00″ which is a check on the arithmetic and corrections applied.

Column 4—Since ordinary log tables give values up to 90° only, it is necessary that the bearings in column 3 are reduced and since by Trigonometry Sin A = Sin (180 – A) also Sin A = – (Sin 360 – A) and Cos. A = Cos. (360 – A). Then when the bearing in column 3 is less than 90° there is no change; when the bearing is greater than 90° and less than 180° subtract the bearing from 180°; when the bearing is greater than 180° and less than 270°, subtract 180° from the bearing; when the bearing is greater than 270° and less than 360° subtract the bearing from 360°. For examples of the above in the form compare columns 3 and 4 opposite stations F, G, E and A.

Column 6 shows the cardinal direction, that is, in which quadrant the direction of the line lies and as the true directions of the lines are found as bearings in column 3 therefore the cardinal direction is with reference to the values in column 3 and not with those in column 4. In the form given the bearing of FG or F to G is 90°·41′·30″ therefore the direction of the line FG lies SE from the point F; similarly direction A to B is SW from A etc.

The form has now been filled up as far it can go without the help of log tables and the surveyor should here determine what accuracy in plotting is necessary for his work and scale. If the scale will not permit of a plot being made to the decimal part of a foot then 4 places for logs will be sufficient, but if as in the case of example in the form plotting is possible to the decimal point of a foot as in most city surveys than 5 places of logs for sides and angles will be necessary.

Again if the distances between stations are only correct to the nearest foot it is evident that any calculation leading to a greater accuracy will only produce a fictitious closing value.

Columns 7, 8, 9, 10.—These columns give the latitude and departure of each distance. Referring to *Fig.* 51 AB is a given distance and ABM (=NAB) its bearing. Here, BM is the latitude of B, or its distance from A along the meridian, and AM is the departure of B or its distance from A along the perpendicular to the meridian.

By Trigonometry AM and BM can at once be found,
for BM (latitude)=AB (distance) × cos ABM (bearing),
and AM (departure)=AB (distance) × sin ABM (bearing), and using logarithms, log latitude = log distance + log cos bearing – 10, and log departure = log distance + log sin bearing – 10.

Thus in the lower compartment of the form the middle line contains the values of log distances and the log cos bearing and log sin bearing diminished by 10 written as shown, both values being extracted from the log book at the same time. The computation for latitude is made upwards and that of departure downwards, as this takes up less room.

The antilog values of latitude and departure are deduced and placed in columns 7, 8, 9 or 10 in accordance with their cardinal direction and since these values are those of B from A (in this case the origin) therefore the values appear on the line for station B etc., etc.

When there is much traversing to be done this method of computation would take up too much time and traverse tables should be used. Traverse tables showing the differences of latitude and departure to every minute of the quadrant by Major-General Boileau, R. E., are perhaps the best known and to use them the procedure is as follows :—

Take the case of the co-ordinates for station B.

Look up in the tables 19° 48′ and since the latitude and departure for 1491·9 feet are required this quantity in the tables will have to be split up into 1000·0 + 400·0 + 90 0 + 1·0 + ·9 = 1491·9 and for 1,000, 400, 90, etc., we obtain the following values.

Latitude.	*Departure.*
940·88	338·73
376·35	135·50
84·68	30·49
·94	·34
·85	·30
1403·70	505·36

Columns a a a a.—It will be observed that the total north and south latitudes is zero or that there is no correction to be applied and that in departures there is a difference of ·4. In a previous paragraph mention has been made as to how this error should be distributed in proportion to distances, but in this case since the error is so small we have + ·2 to be applied to the eastings and – 2 to the westings, and this is done by accrediting the greatest departures with ·1 foot apiece. The traverse is now considered to be *balanced.*

In balancing a traverse the error in closure includes all compensating errors, and it would be more correct to distribute errors in measures made over uneven ground or under adverse circumstances. Linear measures are generally too long, and so it is more correct to apply a greater minus than a plus correction ; again

a slight change in the bearing of a long line would affect the closure more than one in a short line, and so also the bearing of a line at 45°, 135°, 225° and 315° would affect the latitudes and departures equally and in any other direction unequally.

Column 11.—This column is obtained from columns 7 and 8. The difference in latitude between stations A and B will be the total southing made by the line AB, consequently 1403·7 is the latitude of B since A is the origin. With the same argument since C is 704·6 south of B, then the total southing of C from A is 1403·7 + 704·6 = 2108·3 is and eventually it is found that the total southing of E from A is 3276·0. The point F however is in a direction north and therefore F is North of E, so that F with reference to A is 3276·0 − 126 4 = S3149·6, and so on till the traverse returns to A when by rule the northing must equal the southing and thus the southing of I = 1059·5 is equal to the northing of A = 1059·5.

Column 12.—The values in this column are found in exactly the same manner as the values in column 11, except that eastings and westings are dealt with and in the final lines as proof the easting of I = 1308·2 is balanced by the westing of A = 1308·3 − ·1 correction = 1308·2.

Column 13 is a column for successive ordinates by which the double area is obtained. The successive ordinates are found as follows—Add the departures in pairs algebraically considering East being positive and West being negative and enter in column 13. The values in column 12 for A and B are 0 and W 505·4, thus W 505·4 is entered in column 13 opposite station B. The successive ordinates of B and C are both westings, therefore their signs being both minus their result is W 697·2. The successive ordinates for C and D are W 191·8 and E 233·7, and since the signs are opposite and the easting or plus direction is the greater than the result is written as E 41·9. In this column the E and W must be carefully entered as whether the successive ordinate is E or W it becomes plus or minus and influences the next calculation for columns 14 and 15.

Columns 14 *and* 15 are for double areas and are found as follows.—

The successive ordinate is multiplied by the distance on the meridian pertaining to that ordinate. Distances on the meridian are considered as plus or minus according as they are north or south, so the algebraical product with due consideration of signs of columns 7, 8 and 13 is entered in column 14 or 15.

Example W 505·4 × S1403·7 = − 505·4 × − 1403·7.
= + 709,430 for line B.

And similarly + 41·9 × − 522·0 = − 21,871 for line D, etc.

Columns 14 *and* 15 are totalled and the minus double area is subtracted from the plus double area and the result is the double area of the enclosed figure in square feet which can be reduced to acres (for proof see para. 130).

121. Traversing by the bearing method.—The bearing method of traversing is as follows:—Consider fig. 52 and let the theodolite be set up at A and with the two plates clamped at zero let the object glass of the theodolite be brought by the compass into the plane of the magnetic meridian by means of the lower plate which is now clamped. Next release the upper plate and read the forward station B on vernier A (that is the vernier below the vertical arc). The reading will be the magnetic bearing of the line AB. Since the forward station B had to be intersected by means of the slow motion screw the upper plate is therefore clamped and must remain clamped. The instrument is now taken to station B and by loosening the lower plate the wires are made to intersect the back station A, by clamping the lower plate and using the lower slow motion screw. The reading of A vernier should be the same as it was at station A and it should be checked to see that no movement or displacement has taken place. The upper plate is released and the telescope directed to C the forward station and C is intersected by clamping the upper plate and using the slow motion screw.

Now the angle NAB=angle ABS_1 since N_1 S_1 is parallel to N S but the zero at B is in a direction BS_1 opposite to BN_1 or a difference of 180° and therefore the direction BC is the bearing of C from B plus or minus 180° unless B vernier is read or the instrument is transitted. This difference of 180° will occur at every even number station and the last bearing on closing the traverse should agree with the original starting bearing, except that this allowance of 180° must be made if it happens to be an even number station. Distances are measured between stations.

122. Traversing by the inward angle method.—The inward angle method of traversing is as follows:—The direction of proceeding station by station should be counter-clockwise. Set up the theodolite at A (see fig. 52) and level it and if the direction A to J or A to B has not been calculated by an azimuth observation or given as a bearing from another traverse line, clamp the two plates to zero and rotate telescope till the object glass end points to magnetic North by the trough compass using the lower plate and slow motion screw. The compass if of the rectangular

pattern, as is generally the case with modern theodolites, should be taken off and put away after the horizontal angles to stations have been observed. Next release the upper plate and read the back station J and then the forward station B the lower plate remaining clamped throughout the whole of this operation, the readings being read on A vernier or the vernier placed under the vertical arc. As B, will have been read by clamping the upper plate and manipulating the slow motion screw, it stands to reason that the upper plate now remains clamped. Let the readings to J and B according to the field book record (see fig. 53) be 220° 15′ 20″ and 50° 31′ 40″ respectively. The readings are magnetic bearings of J and B and the inward angle at A between J and B is found by subtracting 220°· 15′· 20″ from 50°· 31′· 40″ (+360°) and is 190° 16′ 20″ for the first round.

The lower plate is now unclamped and the telescope is turned to the back station J and the flag at J is intersected by clamping the lower plate and using the slow motion screw. The reading of the vernier should now be examined and it should read 50°31′ 40″, that is, that the forward reading has been set on to the back flag. Now unclamp the upper plate and intersect the forward flag and let the reading be 240° 48′ 20″. The second round thus gives an inward angle of 190° 16′ 40″ and the mean of the two rounds will be 190° 16′ 30″. In the revenue work of the Survey of India it is the custom to also observe and record the outward angle which subtracted from 360° should agree within certain limits with the mean of the inward angles. This angle is a further check, but is really taken for the purpose of simplifying the computations if a traverse has to be set up in a clockwise direction.

The distance between A and B is now measured and is found to be 476·6 feet. A record of crossings and offsets to near detail is also kept. The instrument is now taken and carefully centred over the next mark or station B and levelled. The two plates are clamped, but not to read anything in particular. Let the reading on A vernier be 120° 41′ 40″. The telescope is turned by means of the lower plate towards station A the back station, and the intersection is made by clamping the lower plate and using the lower plate tangent or slow motion screw. The upper plate is released and the telescope pointed to C the forward station and C is intersected by clamping the upper plate and using the upper plate slow motion screw. Let the reading on vernier A be 29° 51′ 00″. The inward angle resulting for the first round is therefore 269° 09′ 20″. The lower plate is now unclamped and the telescope turned to the back station A and the

ower plate is clamped and intersection is made with the lower plate slow motion screw and thus A is intersected with a reading of 29° 51 00" which was the reading of the forward station. The vernier reading is examined to see that no shift has taken place. The upper plate is now unclamped and the telescope turned towards C, and C is intersected by clamping the upper plate and using the upper plate slow motion screw. Let the reading be 299° 00' 20". The inward angle of the second round is therefore 269° 09' 20" and the mean inward angle to be accepted for computation and entry in the traverse form (A) column 2 is 269° 09′ 20″, and so on station by station.

The specimen in fig. 53 is an example of a field book by the **inward angle method.** Recording is to be done *in ink* from bottom of the page upwards.

122. Discussion on merits of both methods.—In previous editions of this book the *bearing* method has been recommended as it is said (1) to eliminate graduation errors since readings are made on all portions of the plate, and this would be true if the inward angle method confined itself to setting on the back station each time with the vernier clamped to 0°, but it has been shown that this is not only not necessary, but time is saved if the starting reading, *viz.* 120° 41′ 40" at station B (*see* field book) is as given at the time of clamping the plates ; (2) it is said to have fewer readings, therefore fewer reading errors. This again is not so, as the setting of the forward reading on the back flag by the inward angle method equalises matters. Any extra number of readings made by the inward angle method are means of checking and a verification of the angle, and this verification is done by the second round being taken over a different part of the graduated plate which cannot happen with the bearing method. (3) With the bearing method, supposing the bearing of a line JK was read incorrectly and entered and recorded as 278° instead of 279°. The reader will understand that this error of 1° will not be carried forward in the observational work as the plates are clamped at 279° and unless the error is detected at the time and the record corrected, the subsequent bearings will still be correct and the traverse might close quite correctly in bearings; but when balanced, if the line JK happened to be a fairly long line, the traverse will disclose a gross error in Northings and Southings, Eastings and Westings. Where the error has occurred cannot be detected, and it might probably be too late to rerun the line. Therefore the argument that by the bearing method any error in reading a bearing effects only the

line to which the bearing pertains may be considered to be rather against than for the retention of this method in preference to the inward angle method. (4) By the inward angle method although the final error in closing includes all accumulative *errors*, yet these errors can be dispersed throughout the traverse since the angles at each station have been observed with as much accuracy as is necessary and without any chance of a *mistake*. It is also to be remembered that the mistake of 1° might have been caused by the traverser manipulating the wrong tangent screw, not an unlikely thing to happen when one's mind is distracted, as it often is, by chainmen and flagmen disregarding instructions. (5) Lastly, it is argued that the compass if watched will disclose any mistakes. This takes it for granted that the compass is of the circular pattern sunk into the upper plate (a relic of 25 years ago and now not made in this manner by first class instrument makers unless specially ordered) and that local attraction at different places along the line is constant. (6) To dispense with the difference of 180° at even stations B vernier might be read at station B for direction of C or the instrument might be transitted and A vernier read. Unfortunately neither of these are free from error as in the first instance any difference in the setting of the verniers (in a 2 vernier instrument) produces an error and in the second instance the collimation error for horizontal angles creeps in as no instrument is strictly free from collimation error and horizontality of axis error and in any case repeated examination and testing for such would be necessary and laborious.

To sum up, any survey system or method which permits of *mistakes* creeping into records must be condemned. The bearing method may be good enough in the hands of a careful and reliable man traversing over a small area and an independent one at that, but when a surveyor has to deal with long lines, and has perhaps to depend on a not too highly skilled agency to help him, he cannot afford to adopt any system but a self-checking one, and it has been found, in India at any rate, that the inward angle system, with at least two angles agreeing, within certain limits, is the best.

123. Measurement of Inward angles.—The following steps therefore are to be followed in measuring inward angles of a traverse (*see* fig. 24).

(1) Level up theodolite after thoroughly centering it over station dot.

(2) Intersect back flag by clamping C_1 and using T_1 (C_2 having been previously clamped).

(3) Read and record value of reading of A vernier.
(4) Unclamp C_2 and intersect forward flag by using T_2.
(5) Read and record value of reading on A vernier.
(6) Unclamp C_1 and intersect back flag by using T_1.
(7) Examine reading which should be as given under (5).
(8) Unclamp C_2 and intersect forward flag by using T_2.
(9) Read and record value of reading on A vernier.
(10) Subtract (3) from (5) and (5) from (9) and if the angles thus deduced disagree by more than the graduation of the instrument, continue till there is a satisfactory agreement.

Footscrews should not be touched between readings.

124. Concerning chains and chaining and measures generally.—For ordinary work the Gunter (66′) or the 100′ chain is used in measuring the distances between stations (*see* also para. 20). The Gunter chain is one of 66′ in length, is lighter and handier, but has this disadvantage over the 100′ chain, in that there are more chain lengths, and therefore more pitching of arrows and greater liability to accumulative error. On more or less flat open ground it cannot be therefore as accurate in measuring distances as the 100′ chain.

In traversing two chains should be used, one a Gunter and one a 100′ chain. The Gunter chain being only as a check on the 100′ chain for the whole distance and therefore the chainmen, not so expert as measurers, are those on the 66′ chain. The traverser should follow the 100′ chain keeping an eye on the alignment of both chains and the correct vertical pitching of all arrows. The traverser must always have with him in his camp a steel tape or a tested 100′ chain in order that he may, morning and evening of a day's work, check and correct his working chains. The chains used on work should be well tried old chains, which do not stretch so readily as new ones. The chain given for testing should never be used on the work and the steel band should be kept dry and clean and when put away for a period, should be oiled and wiped.

The measures of the 100′ foot chain are reduced to the 66′ chain as follows :—

13·66 = recorded long chain measures.
6·83 = ½ ditto.
20·49 = Total

+ ·205 (Add the first three figures of total moved 2 places to the right).
20·695 = reduced chain measure in short chains.

The record of the lengths of the chains at the commencement and end of the work must be made daily so that the correct chain values for computation may be reduced. The mean of the short and long chain is not to be used, but the length of the long chain only. The difference between the short and long chain measures should not be more than $\frac{1}{1000}$.

When traversing of greater exactitude than $\frac{1}{5000}$ is required as would be necessary for City Surveys the steel tape standardised to a certain temperature must be used (*see* paragraph 140). If a greater accuracy than $\frac{1}{10000}$ the line must be staked out and the tops of the stakes or pegs levelled for different sections. Working along streets with a steel band and spring balance handle for tension pull, the reduction of measures for temperature changes and slope and with a theodolite graduated to read 20 secs. there should be not much difficulty in obtaining accuracy to $\frac{1}{17000}$ (*see* paragraph 135). Beyond this limit the cost of survey would increase rapidly and it is worth considering whether the increased cost is compensated for by the increased accuracy.

125. Chaining over uneven ground.—Over uneven ground the changes of slope are best measured with a wooden clinometer, or better still by an Abney's level, the readings being made to a disc held at the other end of the slope at the height of the observer's eye. If an accuracy in chaining of $\frac{1}{1000}$ only is required the chainmen should employ the method of "cutting the chain," that is, holding the chain level by short lengths and plumbing the measure to the ground surface, and if the ground surface is more or less an even slope, the horizontal measure can be obtained since it is equal to the measured distance multiplied by the cosine of the angle of slope.

For accurate work over long distances the crinoline chain has been used. The crinoline chain is of invar metal and is in 5 sections of 66 feet or 330 feet in total length. The plains of northern India have been traversed with this chain in preference to an expensive system of triangulation.

126. How to fold up a Chain.—The chain is gathered up in the following manner. Hold the 50 foot tablet in the right hand and drag the chain till it doubles itself and the handles come together. From the 50 foot tablet end bundle up the chain two links at a time when its shape will be that of a reel or hour glass. The chain should not be undone except systematically The two handles are taken in the left hand and the chain is thrown forward with the right hand, and it will be found by

walking a few yards, holding the handles, that the chain will unravel itself freely.

127. Errors in chaining.—The following are the errors in chaining. (1) Errors in alignment, (2) errors in pitching arrows, (3) errors due to links being bent or doubled, (4) errors due to the small link connections being pulled till they gape, (5) errors due to the small link connections taking up a crosswise instead of a lengthwise position on the chain, (6) mistakes due to counting the number of chains measured and failure to notice that an arrow is missing. For full particulars the reader is referred to paragraph 20.

Tape measures.—Each of the following errors in a 100 foot tape (steel) length will give an error of $\frac{1}{10000}$.

(1) Length of tape giving a difference of $\frac{1}{8}$th inch from the standard.
(2) Error in marking or plumbing $\frac{1}{8}$th inch.
(3) Error in reading $\frac{1}{8}$th inch.
(4) Error in sag or the middle of the tape being 8 inches lower than the ends.
(5) Temperature correction for every 16° (approx).
(6) Tape stretched loosely so that the centre is 8 inches out of line.
(7) The end of the tape being 16 inches out of alignment.
(8) For every 16 lb. pull.
(9) Tape not horizontal or one end 16 inches above or below the other.

(The reader will notice that the above values are either reciprocals or multiples of 8 and as such are as nearly correct as will be found necessary.

1 is accumulative + or —and the constant is to be applied to correct it.

5 is do. do. do. do. do.

4, 6, 7, 9 are accumulative + and can be avoided and in flat areas need not be considered.

8 is compensating and 2 and 3 are mistakes.

128. Field books.—The field book (*see* example given in fig. 53) should be a neat and well kept record. It should be also systematic. The traverser must always remember that he may not himself do the computing or plotting of his work. The space between the two centre lines is for theodolite readings to stations and chain records of the line between stations only. On the right hand side the angles are written, *viz.*, 190° 16′ 20″ and 190° 16′ 40″ and the mean angle is written up in red, *viz.*, 190° 16′ 30″. On

the left hand side the vertical angles taken to forward and back stations usually to the mark on the flags denoting the mean or average height to which the instrument is set up are recorded and also any readings taken to conspicuous objects as intersected points. Readings to intersected points are not to be made except on the *last* setting of the instrument. If this is made a rule the computer will understand that the reading 223° 15 "to palm" was with the theodolite set on the back flag at 50° 31′ 40″. This is an important point to remember. Chain measures corrected for slope should be entered in red. The vertical angles taken are for the purposes of chain reduction only. Traverses having height values can be run with a certain degree of accuracy, but the engineer would find such heights scarcely of any value for his work and a level should be employed in preference; this matter is therefore not treated on or dealt with further. The field book must be written from the bottom of the page upwards. All entries must be made in ink. A sketch plan and a well kept index is very important.

In connection with traversing and its computation the next few paras. are important.

129. To find the distance and bearing between any two points on a traverse.—In fig. 54, 1–2–3—4...10–11–12...18–19 are traverse stations and on the traverse being computed the following co-ordinates were found for stations 1, 10 and 18 respectively:—

Feet.	Feet.	Feet.
N. 1018·6 E. 996·8	N. 4367·5 E. 2018·7	N. 3410·9 W. 608·3

Find the distances and bearings of 1 to 10, 10 to 18 and 18 to 1.

Let the first case be taken that of stations 1 and 10.

Through 10 draw a line 10 K parallel to the initial meridian and through 1 draw a line at right angles to the initial meridian to meet 10K in K.

Then the triangle 1 K 10 is a right-angled triangle of which the side 10K represents the difference of latitude between 10 and 1 and 1 K, which represents the departure between 10 and 1 and these are known and:—

10 K = 3348·9 and K 1 = 1021·9

$$\text{Now tan. angle } 10\ 1\ K = \frac{3348{\cdot}9}{1021{\cdot}9}$$

$$\therefore \text{angle } 10\ 1\ K = 73^\circ\ 1'\ 51''$$

$$\text{Again sine } 10\ 1\ K = \frac{\text{side 10-K}}{\text{side 1-10}} = \frac{3348{\cdot}9}{\text{side 1-10}}$$

$$\therefore \text{Side } 1{\cdot}10 = 3501{\cdot}5 \text{ feet}$$

and similarly the other values for 10 and 18 can be found.

Now the angle M 1 K is a right angle or the bearing of K from station 1 is 90°
and since the angle 10 1 K is equal to 73° 1′ 51″ ∴ the bearing of 1 to 10 = 16° 58′ 9″.

Similarly all the other bearings can be computed.

Now suppose x to be a point intersected from 1. 10 and 18. that is the angle at station 1 was found to be x. 1. 2. Since the bearing 1 to 2 is given in the computations of the traverse and the bearing 1 to 10 has been found, therefore the angle x. 1. 10. is found and similarly the angle x. 10. 1 is found and thus in the triangle x. 10. 1 two angles and the adjacent side 10. 1 are known and therefore the triangle is solved and similarly the triangle 10. 18. x is solved and hence 10. x becomes a common side and the co-ordinates of x with respect to the origin can be computed.

130. Areas.—By successive ordinates or by double departures (DD).

The figure A B C D E F G H I A (*see* Fig. 55) represents the plot of the traverse given in Form (A) (*see* page 140A). Let the successive ordinates opposite ABC, etc., equal y_1, y_2, y_3, y_4, etc.

Let us consider the first double area = + 709,430 square feet which is twice the area ABB′ thus :—

(*a*) Twice area ABB′ = AB′ × BB′ = AB′ × $(y_1 + y_2)$
= − 1,403·7 × (− 505·4 + 0).
= − 1,403·7 × − 505·4.
= + 709,430 square feet.

(*b*) Twice area BB′C′C = area B″B′C′C″ + area BB″x − C″ x C,
and since area BB″ x = area C″ x C by similar triangles.
∴ Twice area BB′C′C = area B″B′C′C″
but area BB′C′C $= \frac{y_2 + y_3}{2} \times$ B′C′
∴ Twice area BB′C′C = $(y_2 + y_3)$ × B′C′
= − 697·2 × − 704·6.
= + 491,245 square feet.

(*c*) Area ODD′ = area GFD + area OD′FG,
and area GFD = CHG (by similar triangles),
= area CC′O + area C′HGO.
∴ Area ODD′ = area CC′O + area C′HGO + area OD′FG,
= area CC′O + area of rectangle C′HD′F.

i.e. area ODD′—area CC′O = area of rectangle C′HDF D

$= JG'' \times B'D'$

$=$ Sum of CC′ and D′D with proper sign × B′D′

$= \frac{D'D - CC'}{2} \times C'D'$

∴ Twice area $= (D'D - CC') \times$ ~~B′D′~~ C′D′

$= (y_4 - y_3) \times$ ~~B′D′~~ C′D′

$= (233{\cdot}7 - 191{\cdot}8) \times -522{\cdot}0$

$= +41{\cdot}9 \times -522{\cdot}0$

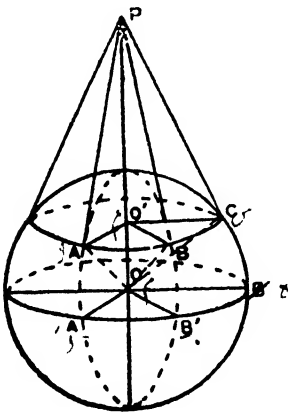
$= -21{,}871$

etc., etc.

131. Convergency of Meridians.—It is usual in a traverse to suppose that the meridians of the stations are parallel to that of the starting station or origin. Provided a station is not far E or W of the origin the meridians of the stations and of origin are practically parallel, though not actually so, as all meridians converge towards each other and meet at the poles. But when the departure (distance E or W of the origin) exceeds, say, 8 or 10 miles there is an appreciable convergency and a correction is necessary for converting apparent to true bearings.

The very slightly curved surface of the earth over which the traverse has been run may be supposed to be flat and tangential to the sphere, within an area of say, 40 or 30 square miles.

Fig. 56.



Let the circle of the figure represent the terrestial sphere, O its centre and r its radius. Let A B C represent a parallel of geographical latitude (λ), passing through a station B of the traverse. Let the meridian that passes through the origin of the traverse cut the parallel in A and let the meridians of A and B cut the equator in A′ and B′ respectively.

Join OA, OB, OC, and let OH be parallel to the plane of the circle ABC. Then CH = λ, and AA′ = BB′ = CH = λ.

Draw the tangents to the sphere at ABC. These tangents lie on the curved surface of a cone whose apex P is such that O′P passes through

the centre O′ of the circle ABC which is the base of the cone. The curved surface PAB represents the plane of the traverse and it is very nearly flat.

Angle BOB′ $= \lambda$ $\therefore$ angle BOP $= \frac{\pi}{2} - \lambda$ and

BP $= r \tan$ BOP $= r \cot \lambda$. Convergency = angle APB $= \frac{AB}{r \cot \lambda} = \frac{d \tan \lambda}{r}$ where $d =$ arc AB and may be taken with approximation = departure of B from A.

Let M = No. of minutes in angle of convergency of B's meridian

$\therefore$ Circular measure of convergency = M sin 1′.

$$\therefore M \sin 1' = \frac{d \tan \lambda}{r} \quad \text{..............................(1)}$$

or $M = d \tan \lambda \times \frac{\operatorname{cosec} 1'}{r} = d \tan \lambda \times K$ (since $\frac{\operatorname{cosec} 1'}{r}$ is constant).

$\therefore \log M = \log d + \log \tan \lambda + \log K$.

If d is expressed in miles $r = 3958{\cdot}06$ (mean radius of earth),

and $\log K = \log \frac{(\operatorname{cosec} 1')}{3958\ 06} = \log \operatorname{cosec} 1' - \log 3958\ 06$.

$= 3{\cdot}536{,}2739 - 3{\cdot}597{,}4824 = \bar{1}{\cdot}9388$.

If d is expressed in feet

$$\log K = \log \left(\frac{\operatorname{cosec} 1'}{3958\ 06 \times 5280}\right) = \log \left(\frac{\operatorname{cosec} 1'}{3958\ 06}\right) - \log 5280.$$

$= \bar{1}\ 9388 - 3{\cdot}7226 = \bar{4}{\cdot}2162$.

In this way it may be shown that $\log K = \bar{2}{\cdot}2161, \bar{4}{\cdot}2162, \bar{2}{\cdot}0357$ or $\bar{1}{\cdot}9388$ according as d is expressed in 100 ft. chains, in feet, in Gunter's chains or in miles.

Example.—What is the convergency for 1 mile in latitude 30° N or very nearly the latitude of Roorkee?

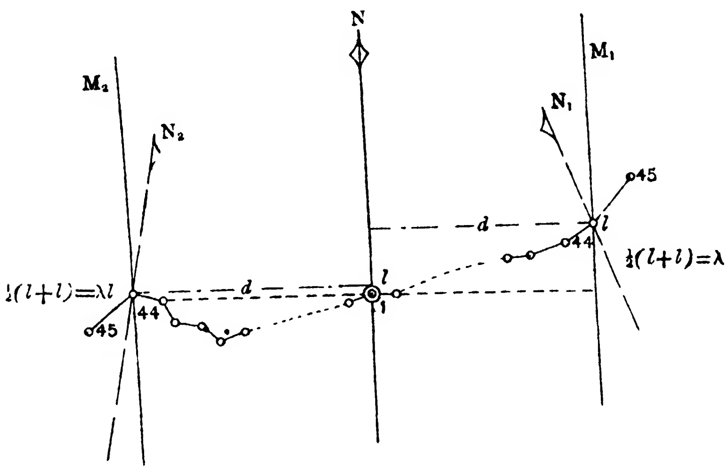
Miles.	Feet.	100′ chains.	66″ chains.
$\bar{1}{\cdot}9388$	$\bar{4}{\cdot}2162$	$2{\cdot}2161$	$\bar{2}{\cdot}0357$ log K.
$\bar{1}{\cdot}7614$	$\bar{1}{\cdot}7614$	$1{\cdot}7614$	$\bar{1}{\cdot}7614$ log tan 30°
$0{\cdot}0000$	$3{\cdot}7226$	$1{\cdot}7226$	$1{\cdot}9031$ log departure
$\bar{1}{\cdot}7002$	$\bar{1}{\cdot}7002$	$\bar{1}{\cdot}7001$	$\bar{1}{\cdot}7002$ log convergency.
·5 mins.	·5 mins.	·5 mins.	·5 mins. convergency

that is in latitude 30° N the convergency per mile is equal to ·30 secs. or ½ minute.

When the points between which the convergency is required are in different latitudes, then the mean of the sum of the latitudes must be substituted for λ or $\lambda' = \frac{1}{2}(l + l')$ in the above formula.

132. The application of convergency correction to a traverse.—Traverses are computed on directions and measurements and the directions are in terms of an initial direction which is usually an azimuth obtained from an astronomical observation, that is, in terms of true North. It therefore stands to reason that at a station East or West of the initial meridian, if an azimuth is observed, the directions, as carried forward on the traverse which are bearings, and in terms of the initial meridian, will not agree with the azimuth taken at a certain station by the amount of the convergence of the two meridians and therefore the azimuth must be reduced to a bearing by adding or subtracting the convergency angle in order to

Fig 57 (*a*).



check the angular work of the traverse. In figure 57 (*a*) it is supposed that 1 is the initial or origin point and that a traverse has been carried to station 44 in an easterly as well as westerly direction and that an azimuth was observed at these stations to check the angular work. M_1 44 and M_2 44 are supposed to be parallel to the initial meridian through station 1 the origin. The azimuthal directions at stations 44 will be N_2 44 and N_1 44 and the angle N_2 44 M_2 and angle M_1 44 N_1 will represent convergency.

Now the azimuth of station 45 from station 44 is in one case N_2-44-45 and in the other case N_1-44-45 and if C = angle of convergency, then the bearing of 45 from 44 will be N_2-44-45 + C when the station 44 is West of the origin and N_1-44-45 − C when the station 44 is East of the origin of survey. Therefore convergency is to be added to the azimuth or

subtracted from the **azimuth** of a station in order to obtain the **bearing** according as the station is West or East of the origin or initial meridian.

In the traverse form at the origin the initial azimuth in column 3 is entered as the bearing and opposite station 44 the bearing of 44 to 45 which is equal to azimuth ± C according as station is $\frac{W}{E}$ of origin. The angles in column 2 are then added down to and cluding station 44 and the total in whole degrees minutes and seconds should agree with the difference of the starting and closing bearing if not a correction + or − is applied and the bearings run down and closed without error. This correction is the angular error in the traverse and hence azimuths with convergency applied is an angular check.

133. Memoranda.—The following points should be remembered in traversing with the theodolite :—(*a*) Much more depends on the accuracy of the chaining than on the angular work. The chaining to a flag 1,000 feet distant may be + 1 foot in error but an error, in reading (not a mistake in reading) would scarcely show any displacement of the flag.

(*b*) The instrument and flags should be properly centred over the station marks, an error of an inch in displacement of either at a distance of 100 feet will produce an angular error of about 3 mins. The angular error increases as the distance decreases and *vice versa*.

(*c*) The permissible error in ordinary traverse chaining may be taken as 1 in 1,000, but in city surveying with a steel band or tape the error should not be greater than 1 in 5000.

(*d*) The chain should be tested against a steel band or an auxiliary chain before and after work and, if possible, once in the middle of the day and the correction applied to all measures accordingly and the corrected value should appear in red ink. Chains stretch, especially new ones, so that the recorded measurements are less than the real.

(*e*) When chaining, the chain should be well shaken as the alignment is being adjusted. The reason for this has been explained already.

(*f*) A chain should be examined for correctness in the intermediate lengths. It might so happen that the chain registers 30 feet or 30 links quite correctly and be a foot or link out at 15, so that a length of 115 feet or links will be possibly a foot wrong. It is for this reason that some surveyors use a reliable tape to measure the final measure which is part of a chain.

(*g*) Chainmen should at every chain length exert the same pull and align themselves automatically between the flags. The last arrow pitched, before the station is reached, should be left till the final measure is examined, checked and entered and also the number of arrows with chainmen. Some chains are fitted with a spring balance and for accurate work the pull can be regulated to counteract any discrepancy in the chain or tape.

(*h*) The centering of the theodolite over each peg cannot be too carefully done, especially when menials are present as it impresses them with the accuracy of requirements necessary for good results. A theodolite fitted with a traversing head saves a good deal of time.

(*i*) The rods or flags should be observed to as low down as possible to obviate the error due to non-perpendicularity.

(*j*) The field record should be in ink and all erasures should be cut out in ink, initialled and dated. The field book should contain an index plan and an index to pages so that data sought can be found with little or no trouble. The field book with its record must be so kept that any computer is able to understand the entries and is able without further reference to set up and compute the traverse.

(*k*) Arrows should be pitched vertically and the chain swung aside so that the chain in its drag will not pull them out of position. Arrows in long grass should have pieces of cloth run through the loops to catch the eye. To define the position of arrows on pavements a chalk line with a fine pencil line in the middle is the best mark.

(*l*) On the final part of the chain measurement, it should be a rule that the chain is dragged past the station and aligned on the back station. The chain measure will then be given as so many chains and so many links or feet.

[If the forward end of the chain reached the mark and the chainman held the chain against the last arrow it is quite possible, and in fact so often happens, and it is noted here as a precaution, that he will call say 74 feet instead of 26 feet. The same mistake may happen with the steel tape by holding the 100 feet at the station mark and obtaining the tally at the arrow from the chainman.]

(*m*) Offsets should be taken by means of a crosshead or optical square and metallic tape. The measuring chains should not be used for offset work.

(*n*) Measurements must be done "pari passu" with the angular work.

(o) As levelment does not effect horizontal angles much and a slight deviation of the bubble, little or nothing, the bubble should *never* be corrected during observations (*see* paragraph 65).

The squad required for ordinary traversing with two chains going will be as follows:—Chainmen 4, flagmen 2, menials for instruments and umbrella 2, and possibly an "axeman" or line clearer. Total 8 as a minimum and 9 as a maximum.

134. City Surveying.—City surveying demands from the engineer and surveyor a higher order in accuracy than that of farms or property in an agricultural or depopulated area. The accuracy may be said to increase in proportion to the value of property, bearing in mind also that, in well established ports and commercial centres, ground rents and building sites may yearly increase in value and thus in some cities and also in certain quarters of some cities the highest class of surveying as regards accuracy is an absolute necessity. Probably its main object is to avoid litigation and thus the survey map becomes the supreme court of settlement.

However the aim in accuracy should not be so much *great* precision as the *required* precision under the circumstances, and on this the cost of the survey should be worked out, the municipality or governing body on the one hand tabulating a list of detail it requires shown and the surveyor then selecting the scale or scales on which the city area is to be surveyed. If the municipality decides the scale, amount of detail, etc., the surveyor is left with the question of accuracy to which he must work to satisfy the requirements laid down. Again, the size of the scale will decide whether the actual plot is to be the legal map from which all measurements are to be taken, or whether measurements are to be printed along the lines of a conventional plot. If the scale is a large one, say 20 feet to the inch, it would be folly to suppose such a map was intended as a guide map for printed measurements, rather it should be a map plotted accurately to all measurements and from which areas and detail can be calculated.

In a city survey the framework must first be considered and that framework will in all probability be a theodolite traverse in preference to triangulation. Triangulation would not only be expensive but possible only from the tops of houses and the points thus fixed would have to be transferred to the ground level.

135. Precision required.—As theodolite traverses would all be closed traverses there necessarily arises the question of the required

precision and that required precision will have been attained when on the closing error of a traverse being dispersed no station, according to scale, will contain a plottable error. On scales of 25 to 50 feet to the inch values to one-tenth part of a foot may be considered as plottable, or at any rate values to this accuracy or a slightly greater accuracy should be aimed at in the computation, in which case measurements, latitudes and departures, should be taken to the second place of decimals of a foot. Tape measures of lengths are therefore required to the part of an inch.

The error of closure should be perhaps within $\frac{1}{10000}$ where error of closure $E = \sqrt{\frac{(\text{error in latitude})^2 + (\text{error in departure})^2}{\text{perimeter.}}}$

For example in a 10,000 feet perimeter which is a little less than two miles if a traverse is found to be ·6 feet error in latitude and ·8 feet error in departure we get from the formula $E = \sqrt{\frac{(\cdot 6)^2 + (\cdot 8^2)}{10{,}000}} = \frac{1}{10{,}000}$

The accuracy of closure of a traverse of this description to between $\frac{1}{2}$ and $\frac{2}{3}$ of a foot seems reasonable to expect, and when such an error is dispersed or distributed through 50 stations of an average distance of 200 feet ap^-t, the plottable error might be considered *nil.*

It has been already shown that some errors are accumulative and some compensating and therefore a few important main lines common to main traverse circuits may be required to be accurate to $\frac{1}{17{,}000}$.

It must be remembered that the areas will be calculated from the traverses, so the distribution of error in precise work should be carefully done and as follows:—

The error per side in latitude $= \frac{\text{total error in lat}}{\text{perimeter}} \times$ length of the side,

and the error per side in departure $= \frac{\text{total error in departure}}{\text{perimeter}} \times$ length of side.

The slide rule will be found a quick and accurate method for the above.

136. Angular precision.—As regards the angular work it will be found that a transit theodolite with traversing head (sometimes known as railway pattern stand) reading to 20 secs. with 3 repeat readings will suffice, but it is doubtful whether a 6 or 8 inch micrometer reading to 10 secs. and estimation to 2 secs. with one extra check angle would not be a more suitable instrument when traffic is liable to vitiate several repeat readings.

The angular correction to the traverse should be based on the system of closure of angles of a polygon and the excess or defect distributed equally. If this is admitted then there arises the question of azimuths to control the angular error, and as both azimuths and the sum of the interior angles of the polygon must rule the angular correction, a judicious selection of the azimuthal stations must be made, and the angular correction through several blocks distributed before any balancing can be done.

The probable angular error per station would be the total error divided by the square root of the number of stations. There being two conditions to satisfy it must arise that many azimuth stations would tend to confuse and complicate matters.

137. Origin and method of subdivision.—There is no need to have more than one origin for ordinary sized cities. True, the co-ordinates may seem to be unwieldy, running into thousands, but the full set of figures need only appear once on the top of each page and at each change in the thousands.

The city might be supposed to be divided up into main traverse blocks wards or any such municipal administrative areas (perhaps it would be most convenient for compilation to adhere to some municipal rather than survey units), each block being roughly about ½ square mile. The common line between blocks of main traverses should be traversed twice and in opposite directions and the mean accepted for each block so that the stations along the common line will agree. No error can, therefore, be distributed unless it is distributed to each block on the common line. It will thus be seen that the traverse main network for the whole should be set up and balanced before these blocks can be divided up by sub-circuits into smaller areas.

138. Main circuits.—The main traverses should have permanently marked stations, known as monuments, the positions of which should be properly selected and fixed also by accurate measurements to adjacent permanent marks. The main traverses will be run in the most convenient way and along lines of least resistance and not with the sole view of aiding detail work. The distance between main traverse stations should be as great as possible, as then compensating errors in tape lengths will permit of the measure being nearer the truth.

139. Sub-circuits and tie-lines.—Sub-circuits and tie lines will be run from these main traverses up all streets and possibly alleys and by-lanes and the stations of these sub-circuits should, considering the scale, be so placed that on plotting, at least five or six will appear on the

sheet of paper used for detail work. The detail work may be carried out by tape and offset methods and the work to be plotted direct on the table as it proceeds, or by telemeter methods with the Tacheometric planetable. With the former the surveyor must be careful to work from the greater to the less and not *vice versa*, that is, in a given block it would be correct to divide up the block by supplementary tie lines and to fill up the resulting small blocks after the tie lines close and are checked. It would be incorrect to start detail work on the whole block in one corner and continue filling up the block, as then the error will be accumulative and an impossible one to disperse.

140. Check for chain.—A standard at mean temperature measuring 100 feet should be set up at the city head-quarters, such as a town hall or municipal offices, and all steel tapes and other classes of tapes used should be standardised to this measure and in the future in case of disputes arising as to ownership, etc., this standard should be referred to. Any point needing settlement should be submitted to the proper authorities to adjudicate on and the map drawn accordingly.

141. Levels.—City levelling should be levelling of precision and level values should be given where the city authorities are likely to require them. The sites selected for bench marks should be of a permanent character.

142. Details.—Street lamps, hydrants, manholes, subways, etc., should be accurately shown on the map in conventional colours ; those below or above ground level should not be confused with those at ground level.

The demarcation of the drainage system for houses and streets and the outlets for sullage water should carefully be attended to. The widths of streets and pavements and up to which limit they are paved or otherwise should be given. Property belonging to harbour, railway and other large landowners should be measured along their boundaries, and where insufficient marks exist or where the boundary is doubtful these facts should be noted and settled. The corners of all street blocks near monuments should be measured to and recorded in a proper manner, and, if necessary, the measures should be entered on the map. When the map has once been plotted and examined the field books should be considered of no further value. Either the plot of the map or the added measures must be considered sufficient and no satisfaction can be had from field books which contain offset information and not direct measures or diagonals. All

measures printed on the map must be direct measures and not measures deduced from offsets.

The geographical situation of detail in a city survey is of no practical use whatever, so that traverse co-ordinates need not necessarily be joined on to adjacent geodetic data. An index map on a small scale can easily be compiled as the mapping proceeds and the reduced plan can be made to fit on to two or three data common to both.

City surveying is mostly carried on at night or when traffic more or less ceases. The planetable methods, *see* Tacheometric surveying, is eminently adapted for city work as stadia observations can be made and distances obtained without fear of interference by traffic.

What has been written is applicable to city surveys to be used by the engineer for construction, improvement, etc. The Ordnance Survey of England does not undertake to settle ownership of property and for general use a scale of $\frac{1}{500}$ has been found large enough for all municipal purposes. Any survey on a scale of 20 feet to the inch becomes a working plan. In India the Government requires railway location work on a scale of 400 feet to an inch, and, if so, town planning and city improvement must suggest a larger scale and possibly 200 or an even number of feet to the inch would be required; bazaars and crowded areas have been surveyed on scale of 24 and 36 inches to the mile but scales as integral parts of a mile have no meaning to the engineer especially in drawing up his estimates and his scales should be in feet.

The plan drawing should not contain shade lines for buildings as confusion arises as to whether the inner or outer edge of the shade line is the measured limit.

CHAPTER VI.

THE PLANETABLE AND ITS USES.

143. General.—The planetable and its method of use in surveying is due to the Survey of India who originated it and who still use the simple table, plain sight rule and tangent clinometer. These are considered the best under the climatic conditions prevailing and in the hands of the Indian staff which is now almost entirely employed on this class of work.

The scale of the survey is a great factor in determining as to whether the planetable is to be used or not. The smaller the scale, the greater the desirability of surveying with the planetable, especially in hilly ground. On very large scales, where extreme accuracy is required together with records of distances and angles, the planetable loses its value, though even here, it may be judiciously employed. In dense jungle and undergrowth it has been thought that the planetable is an impossible instrument and yet all the forest areas of India were surveyed entirely by the planetable, and it is doubtful, whether these areas could have been mapped by any other system, except at a great expense of clearing, plotting and adjusting.

Two kinds of planetable equipment need only be described, namely (i) the simple planetable and stand with its plain sight rule magnetic compass and tangent clinometer, (*see* para. 83) and (ii) the elaborate aluminium table with telescope alidade, or sight rule head as it is sometimes called. (See Chapter II, Part II.) All other planetable equipments might be said to be either an elaboration of the one or a modification of the other; the former might be said to employ planetabling methods pure and simple and the latter to combine with such methods tacheometric or stadia methods.

144. The simple planetable equipment.—The table is made up of two pieces of well seasoned pine about ¾ inch thick braced underneath by two battens of harder wood (usually teak) having slot holes to allow for contraction and expansion. In the centre underneath is fitted a bossed head of brass which when placed on the tribach of the stand is clamped to the tribach by means of a fly nut screw having a washer. The

slit legs of the stand are connected to the tribach by a bolt passing through two holes and wing of the tribach. This bolt is wormed at each extremity and two antagonistic fly nut screws secure the legs and hold them tightly clamped. This antagonistic action has the tendency to squeeze the extremities of the legs to the tribach and not to split the wood along the grain, as often happens with the bolt head and nut device.

When the planetable is placed on the top of the tripod so that the bossed head passes through the hole it is screwed home and clamped by the screw and the table is complete. There is no clamp, slow motion or footscrews with this equipment, and under ordinary circumstances no necessity has been found for them.

145. How to mount paper on a planetable (*see* also para. 3).—Cut a piece of white or blue hand made drawing paper so that it is roughly ½" smaller all round than the table. Next cut strips of strong foolscap, or cartridge paper, about 4" in width and with a total length of the perimeter of the table with a little to spare. Prepare some thin paste and rid it of all lumps and having *well soaked* the strips of foolscap apply the paste on one side of the strips only and keep them handy. Pass the drawing paper through a tub of clean water by holding two corners of the paper, care being taken that the surface of the paper is not bruised or cockled. Surplus water should be allowed to run off and the paper placed right side up as centrally as possible on the table. If there is an assistant the paper being held by four corners should be allowed to first touch the centre of the table and then the edges laid down. No sponging should be attempted as it removes the sizing. Now take the thin strips already pasted and paste down the edges of the drawing paper by overlapping it and turning the outer edges of the strips beneath the table. Put away in a cool place to dry. The pasting down of the thin strips should be done as soon as possible as no portion of the drawing paper should be permitted to dry before this operation has been performed. It may be necessary from time to time to apply a little paste here and there during the drying process. If the quality of foolscap used is found to be weak, when the tension due to contraction of paper asserts itself, then tracing cloth is an excellent substitute. The map can be removed by passing a penknife under the paper.

If the drawing paper is to be mounted on cloth a piece of open mesh cloth about 6" larger all round than the top of the table should be cut and well rubbed in water to rid it of starch. The cloth should next be

rinsed fairly dry and pulled by opposite corners with zigzag motion to stretch it to its utmost. Place this cloth on to the table and apply paste to the edges and stick the cloth all around to the *underneath* portion of the table. This done apply paste to the exposed cloth, on the top of the table, evenly and free of all lumps. Take the drawing paper previously cut smaller by half an inch than the table and pass it through a tub of clean water and place it centrally right side up on to the paste covered cloth and with a piece of clean blotting paper between the hand and the working surface of the paper press the paper from the centre outwards in all directions.

Paste thin strips of foolscap along the edges to protect them from being torn up by the sight rule. The board should be left in a cool place to dry. To remove the map cut around the edges and with an office ruler roll the drawing off the board. The paper mounted over cloth gives a much better working surface and the map of course will last much longer.

Good results in mounting will aways be obtained if the paper is laid well to start with and the edges dry before the central portion. The board should never be wetted as it is bound to give trouble later.

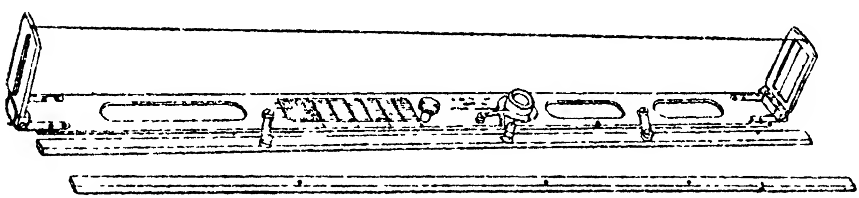
Two men can usually do as many as twelve standard size plane-tables in an hour, and if such work is done at about sundown or a little earlier, by next morning, unless the weather is very damp, the paper will have regained its smooth even surface and if not absolutely dry will at least be fit to plot on. In India the difficulty is to keep tables from drying too quickly and therefore the drying is usually done over night. Such implements as clamps, drawing pins, and pin strips are a nuisance, as they obstruct the proper working of the sight rule and after all are of little or no use in a high wind. The planetabler who wishes to do good work and retain his temper will do well to consider a quarter of an hour well spent in mounting his table.

146. Sight rule and magnetic compass.—The ordinary sight rule is a piece of flat wood about 2" broad and ¼" thick and 20" long at each end of which is mounted a brass vane. If the planetabler is right handed the fiducial edge is on the right and the nearer vane will be the sight vane and further vane the observation vane. The sight vane is pierced with a slit about one-sixteenth of an inch wide or less and the observation vane has a broad aperture in the centre of which is stretched vertically either fine brass wire or better still horse hair, which can be

renewed at any time by being plugged in by small pegs or a whittled match.

The conditions required in a sight rule are, that on a line being drawn along the fiducial edge when the ruler is turned end to end and placed along the line, the edge should lie evenly along the line and also that the line between the sights or the line of sight should be parallel to this ruling edge. For objects much above or below the horizontal plane of the table a thread is stretched from vane to vane and high objects are intersected through the peep hole along this thread and low objects by the thread intersecting the object on the wire of the observation vane.

Fig. 58.



The illustration (fig. 58) is of an improved pattern sight rule devised by the author. It is of electrum, has a separate slide for its fiducial edge, bubble for levelment of table, collapsible vanes, engraved scale and points for rough stadia measures. The button, in the centre or at the point of balance, is for lifting the rule. Messrs. E. R. Watts & Son, the makers, call it the "Indian" pattern.

The magnetic compass is of the ordinary trough pattern with a needle five inches long.

A description of the sight rule in use at the Thomason College is here given. The rule is of box-wood of size 20″ × 1½″ × ⅓″. The sight vane and the peep vane are of brass hinged at one end so as to fold flat when not in use. In the rule is countersunk a circular pill-box bubble and also a magnetic needle which has a stud for throwing it off its pivot when not in use. This self-contained sight rule has been found in practice to be most useful and has given excellent results.

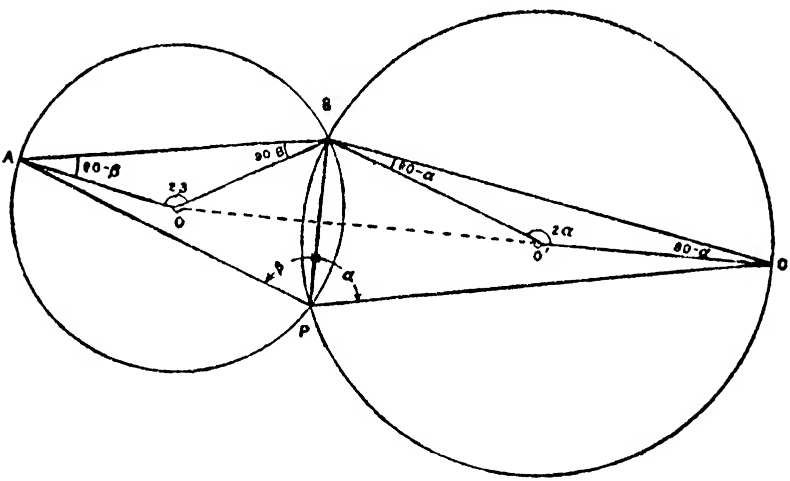
147. Methods of Survey.—The simple planetable and its accessories have now been explained and survey work with it may be classified as (i) a planetable survey by magnetic bearings; (ii) a planetable survey

by the back and forward ray system; and (iii) planetabling proper by intersection and interpolation based on trigonometrical or theodolite traverse data.

The two first stated methods are useful in their way and at times probably the most effective means of doing some classes of ground, but before these are entered into in any detail it is essential that the graphical method by which the planetable solves and finds its position by interpolation or resection should be explained as it is here that it possesses its greatest asset and hence its extended use in topography.

148. Geometrical proof.—If A, B and C (fig. 59) are three known points and P a position at which the table is situated (the whole table for most scales may be taken as a point) then if the table were set

Fig 59.



in true azimuth, rays drawn from the projections of A B and C will meet at the point P, when the angles APB and BPC are known. The point P, with respect to AB will be situated on the circumference of a circle drawn through ABP, and the point P, with respect to BC will be on the circumference of a circle drawn through PBC. The intersections of the two circles will be at B, a point common to AB and BC, and P which will be the required point.

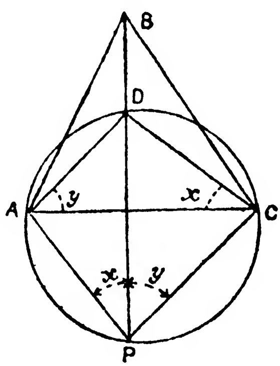
By Euclid III, 20, the angle at the centre of a circle is twice the angle at the circumference standing on the same arc. Let AB be this arc. If we make the angles BAO and ABO each = 90°—APB, the angle AOB will equal twice APB therefore O where AO and BO intersect, is the centre of one of the circles required, and similarly if the angles O′BC and BCO′ are made equal to 90°—BPC then O′ is the centre of the other circle; with a radius OA and a radius O′B draw the two circles, and P the intersection of the two circles other than B will be the required point.

When one of the angles is obtuse, the complement of it is to be used and the angle thus found protracted on the opposite side of the line joining the two known points to that on which the required point P is.

It follows also by Euclid III, 22, that if the angles ABC and APC are together equal to 180°, that the centres O and O′ will coincide and the solution is indeterminate, and hence we obtain the rule that if A B C and P are points situated on the circumference of a circle the point P is indeterminate.

149. Trigonometrical proof.—Let A B and C be three known points and P the station from which the angles x and y have been observed.

Fig. 60.



Through the points ACP pass a circle and let this circle cut the line BP in D. Join AD and DC. By Euclid III, 27, the angle DAC = y and angle DCA = x. Then in the triangle ADC the side AC and the two adjacent angles are known (AC is known as every function of the triangle ABC is given) and therefore the side AD is known.

In the triangle ADB since AD and AB are known and the angle BAD = angle BAC—angle DAC therefore the angle ABD is known.

In the triangle ABP the angle BAP is known, since it is equal to 180° – (angle ABP + x), and the side AB is known, therefore PA and PB are found. In the same way PC can be found. If B coincide with D then the point P is indeterminate. For tabulated proof suited to logarithmic computation reference should be made to Chapter I, Part II, on Triangulation (*see* problem of fixing a station from three known points).

From the foregoing proof it will be seen that if the angles at P are observed with a theodolite and the angles plotted or pro-

tracted on a piece of tracing paper that the point P can be pricked through when the lines PA, PB, PC pass simultaneously through the points A B and C.

150. The station pointer.—An instrument called the "station pointer" serves the same purpose as the sight rule of graphically solving the three point problem but the values of the angles must be known and protracted on the arc to which the three arms are attached, the central one being fixed and the two outer ones being movable. Such an instrument is largely used on marine and hydrographical surveys when points on the shore are known and the angles between them are observed with a sextant. This fixes the position of the observer, say in a boat and on a sounding being taken the depth of water at a certain point or distance from the shore line is found.

151. Graphical methods.—To find the point graphically with the planetable there are several methods but of all these there is none so simple as the trial or "triangle of error" method which has been in use in India for at least half a century to the exclusion of all others.

152. Bessell's method.—This method or as it is sometimes called the ABC solution finds the point after four or five movements of the table and fails very often since the intersection of two of the rays may fall off the table, or the intersection point which is used for setting on a third point, is so close to the third point, that the setting being short, the azimuth of the table is faulty. Long pencil lines have to be drawn on the table and a succession of these for every fixing would soon make the paper and map dirty. Bessel's solution is based on the geometric principle "that in any inscribed quadrilateral the angle made by one of the sides with one of the diagonals is equal to the angle made by the opposite side with the other diagonal."

153. The Tracing paper method.—On reconnaissance work the tracing paper device is sometimes resorted to and the method is as follows:—On the planetable being roughly put into orientation, rays from any point on a piece of tracing paper or cloth are drawn to three or more known points. The tracing paper is then shifted about till the three rays pass simultaneously through the points from which they have been drawn when the point which is the vertex of the rays and was an assumed position, becomes now the true position and is pricked through. Then with the point thus found and the sight rule set on the projection of this point

and the projection of the most distant known point, and on the distant point being intersected, the table will be in true orientation or true azimuth, as it will hereafter be termed.

154. Llano's method.—This method is that in which the operator is required to bisect the line AB (*see* fig. 59) and then draw a perpendicular, sighting the line thus drawn on B, etc., etc. This method is useful to know possibly only from an academic point of view, and as a practical method, must be held inferior to the trial method, since a certain amount of geometrical construction is involved into which there must necessarily creep some constructional error and further the method is unwieldy necessitating large compasses, drawing of arcs, etc.

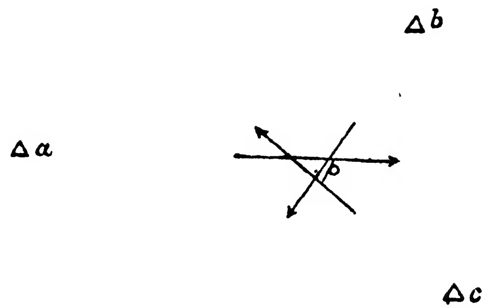
155. The "triangle of error" method.—In the trial or triangle of error method two conditions arise when P the point sought is situated (i) *within* and (ii) *without* the triangle formed by the three known points.

If A, B and C are three known points on the ground represented by *a b* and *c* their projections respectively on the table, and if the table is in true azimuth with respect to these three known points then the rays drawn through *a b* and *c* with the directions of A, B and C will intersect at a point *p* which will represent P on the ground. This rarely happens since the table cannot be set in azimuth at the first trial, even with a magnetic compass the variation of which is known, and hence instead of obtaining an intersection at *p*, a triangle is formed, which is known as the triangle of error. This triangle of error will be great or small depending upon how much or how little the table is out of azimuth.

156. When point sought lies within the triangle.—This condition leads to the solution of the triangle of error from *within*, that is to say the point *p* on the table will be *within* the triangle of error and will be in a position such that the perpendiculars from the point *p* to the rays drawn from *a*, *b* and *c*, will be in proportion to the distance of the point *p* from the points *a*, *b* and *c* respectively.

In figure 61 the point p is about equidistant from b and c and a little further away from a, and as p is *within* the triangle formed by joining a b and c then p will be approximately as given. If now the rays are rubbed out and the sight rule set on p a, and A be intersected, the next trial will fix p or in other words the rays from a b and c will intersect exactly at p. If they do not then a second and nearer approximation is made and so forth. Generally two approximations are sufficient to find the exact point p. Again if the estimation of p could be made correctly at the first trial one approximation would be sufficient.

Fig. 61.

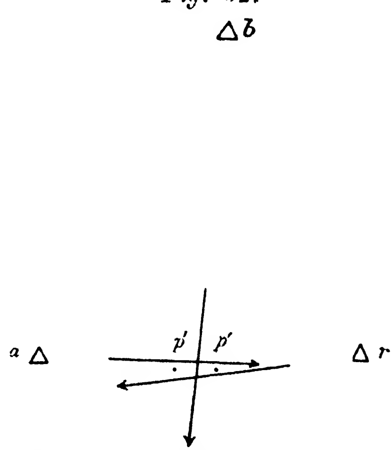


The position of p as found *within* the triangle is strong, but possibly the **strongest position** is when p is very near one of the points a, b or c.

It should be noticed that if arrowheads are affixed to the rays as drawn *towards* the observer the point p falls always to one side; in the case in the example always to the left of every ray. This will be useful to remember later on.

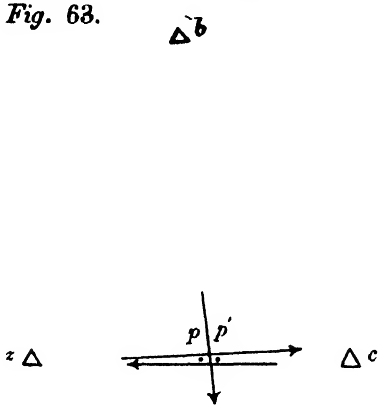
Let the condition now be considered when the point sought lies within the triangle but near the line joining the two points, Fig. 62. Let the rays be drawn as in figure and let arrow heads be affixed. On the point p being found and the board orientated the direction of movement of the error in the ray must be proportionate to the distance away of the points and be all in one direction; p therefore is the point and not p', as p' is on the reverse side for one ray. The value of the position of p is strongest when the ray from b is more or less at right angles to the rays from a and c, and weakest when b lies near a or c for the intersections then would be very acute. The value of p increases in strength also as b approaches p.

Fig. 62.



The same solution and the relative importance of strength holds good when the point p is just without the triangle. It will be noticed that although p in both cases falls to the left of all rays yet in one case it is situated *within* and in the other case *without* the triangle of error.

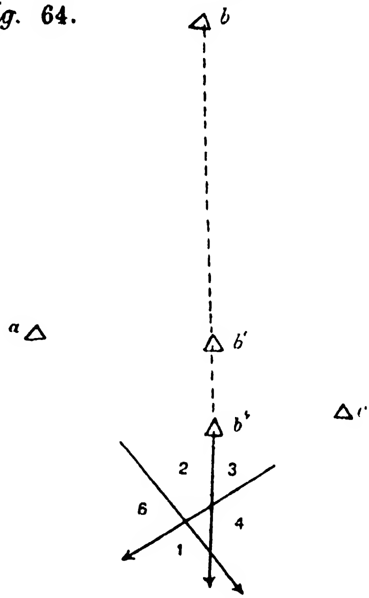
Fig. 63.



157. When the point sought is without the triangle.—This condition (Fig. 64) leads to the solution of the triangle of error from without and the point p will fall without triangle of error formed by the rays drawn from a b and c on A, B and C.

To return to the theory of arrowheads and the rotation of the board it can be seen, Fig. 64, that p cannot lie in the positions 1 and 2, 3 or 5 since in each case one of the rays gives an apparent contrary motion to the other two. There remains the positions 4 and 6 where the rays rotate in the same direction. Again as the condition of proportional distance to the rays must also be considered, for p to be in a position at 4 is impossible, since b is further away than a and c, in about the proportion of $2\frac{1}{2}$ to 1, and therefore the position at 6 is the only possible position and p is therefore approximated at 6 as about 1, 1 and $2\frac{1}{2}$ units from the rays a c and b respectively.

Fig. 64.



Let now the position of b be changed to b then again with the above reasoning the position 6 becomes impossible and the position of 4 possible. The reader will now say, since such is the case, there must be some position of b when p will neither be in 6 or in 4 but somewhere between, exactly so, and when it is neither one thing nor the other, is when b is so situated that a b c and p are on the circumference of the same circle, and hence p, as has been proved, is indeterminate.

As to whether the point is at 4 or 6 the following rule will make it clear "**when the point sought is without the triangle, it is always on the same side of the line from the most distant point as the intersection of the other two lines.**"

The further b is away from p the weaker the value of the position and the position only becomes a strong one when p is very near b. In Fig 64 if b'' be the near position it will be seen that since b, b′ and b'' are all in one and the same straight line the triangle of error remains the same but the approximation of p will be close to the ray from b and occupy a much more definite position than when at b' and so on. These two conditions practically include all the cases which will occur in practice, and whether the solution is a strong or a weak one, should be thoroughly understood.

In speaking of the three point problem it must not be taken for granted that if a fourth point is seen it must not also be used, on the contrary, a fourth ray may be extremely useful in the solution and the point when found will be above suspicion.

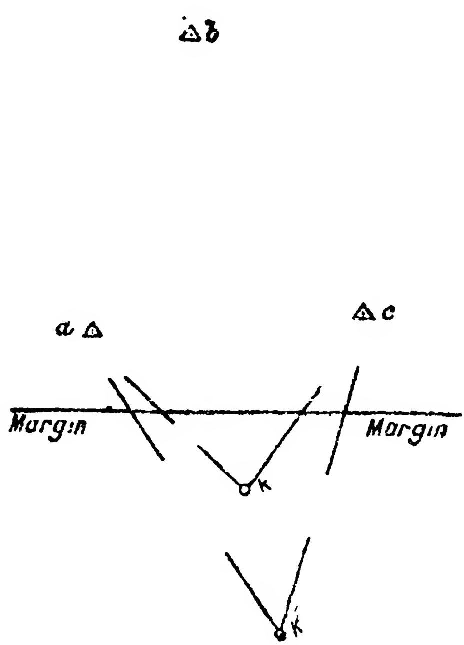
158. Approximating position.—The triangle of error as has been stated depends entirely on the azimuth of the board and with a magnetic compass the variation of which is known to be fairly constant, the point sought should be found on the first and certainly on the second approximation, but the planetabler with a little experience will generally find two points out of the many around him which will be found in a line or can be placed in a line by moving the table, and with the sight rule on their plots, the board can be brought into exact orientation by intersecting the more distant one of the two, and thus the position sought is found almost at once by resection from one other. Again if two points are not exactly in line and if it is considered that a line drawn from the distant one will pass by the other at 50, 60, 100 or 200′ as an offset, judging by the eye, and the allowance is made in setting the sight rule it will be found that one further approximation, if any, is sufficient. When a planetabler says, "I am between these two points and I have this point near and at right angles," "or these two points are in a line and this other will give me a good cross in intersection" it may be taken for granted he knows a good deal about the art of interpolation or "fixing" which term will in future be used as an abbreviation for fixing the position of the table.

159. Here it might be noted that, although the fixing *outside* the triangle is geometrically true, yet many issues are involved—that of poor plotting, inaccurate co-ordinate squares, unequal expansion and con-

traction of table, inaccuracy in the fiducial edge of the sight rule and lastly small differences in the fixing of the planetabler's auxiliary points, some or all of which are being used, that this class of fixing should be adopted with caution, since any inaccuracy tends to intensify the weakness of such a fixing; whereas a fixing within a triangle if it will not solve absolutely owing to some slight errors, then at least the error in position is ultimately confined to a very small triangle somewhere within which is the true or mean point to be used. The fixing without the triangle is always avoided by the expert planetabler who foreseeing such a contingency throws out a point outside his margin of work, it may be, so as to place him always *within*.

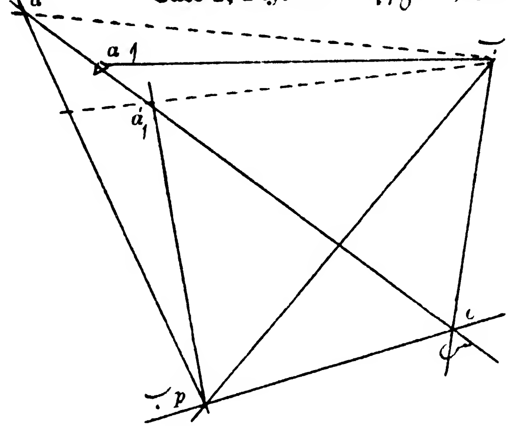
In figure 65 the contingency is illustrated where work up to a certain line or margin was necessary. A point K and a point K′ are intersected from *a* and *c* and although there are only two rays to K and K′ their positions are so to speak approximate but K could be used with absolute confidence and will give no error in a fixing even if K or K′ were a little incorrect so long as the position of the table is within the cone of the two rays to K or K′ respectively; in any case a fixing with *a*, *c* and K or *a*, *c* and K′ would be *within* the triangle, more accurate than the fixing *without* the triangle with the points *a* *b* and *c* which since *b* is more distant than *a* and *c*, is geometrically weak. Some surveyors place an implicit belief in the solution without the triangle, and it is not the writer's intention to say they are wrong or incorrect; he merely states his preference and in his personal experience he has invariably avoided the fixing without the triangle except when the middle point is much nearer than the other two used.

Fig. 65.

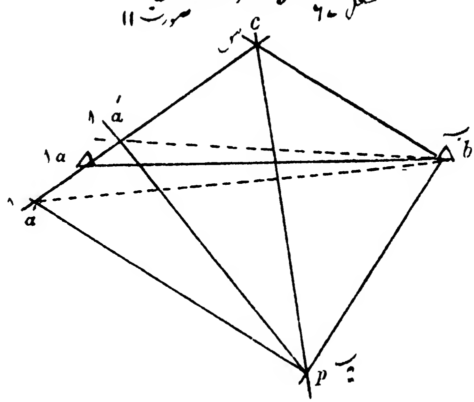


160. The two point problem.—Let A and B be two inaccessible objects as the spires of temples or hill peaks. They may, as in case I. be both on one side of the planetabler or in case II one on each hand. Let the plots of A and B be given as *a* and *b*. At any position C on the ground, preferably on fairly high ground or in a conspicuous position, set up the table and with the compass bring the table into approximate azimuth. Sight A and draw a ray *ac* and again sight B and draw a ray *bc* and consider *c*, the intersection, as the plot of *c*. With the sight rule on *c* draw a ray *cp* to another object P and produce the ray for back and forward setting. Leave a mark at *c* and proceed to P. At P set up the table and with the sight rule along the ray *cp* intersect the object or flag at C.

Case I, Fig. 66.



Case II, Fig. 67.



This back and forward setting over positions P and C must be very carefully done. Now intersect B and draw a ray, *bp* to cut the line *cp* in *p*. With the sight rule on *p* intersect A and draw a ray and if A is intersected in *a*, *p* is the true position, if not, let *pa'* be the ray, cutting *ca* or *ca* produced in *a'*. Join *ba*. The angle *a'ba* will represent the azimuthal error of the table, and if we can disperse this error we will have three rays to fix the position of P one from *a*, one from *b*, and the third being the true meridian.

Place the sight rule on the line *a'b*, sight and note any object intersected, next place the sight rule on the line *ab*, unclamp the table and clamp it again (with the sight rule on *ab*), on the object previously selected as being intersected on the line *a b*. The table will be now in true azimuth; so intersect from *a* and *b* and the true position of P will have been found.

~~Fig. 68.~~ شكل ٦٨

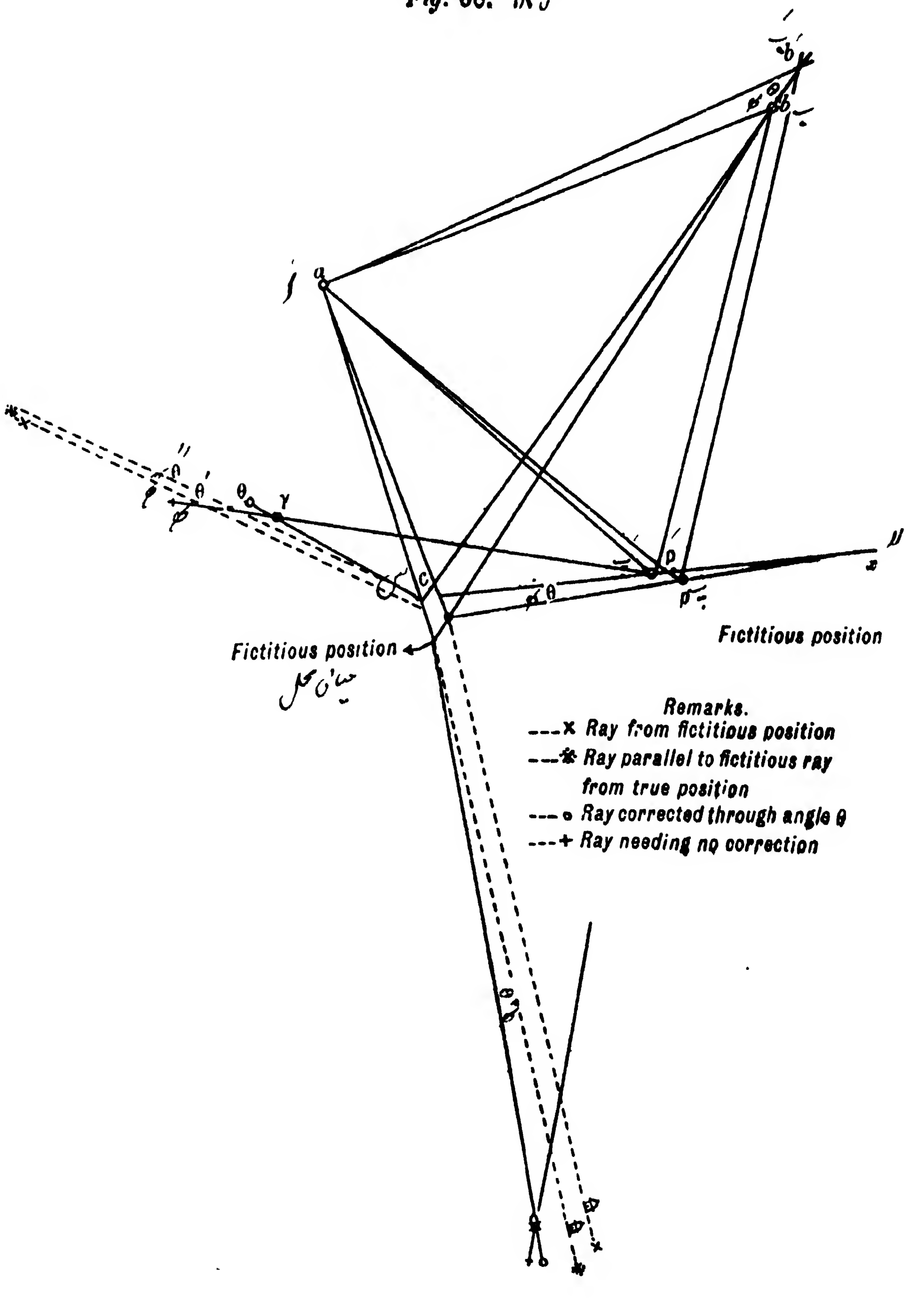

b
b
a
γ
θ'
θ₀
c
p
p
θ
Fictitious position
Fictitious position
Remarks.
---× Ray from fictitious position
---✱ Ray parallel to fictitious ray from true position
---∘ Ray corrected through angle θ
---+ Ray needing no correction

Fig 68 shows an actual case of the fictitious position of p becoming p' and c corrected to c'.

To correct c to c'.—From p' draw a ray to C and the ray will no longer pass through c but c' and the true position of C must exist along the ray p' c'. Now the angle of correction $= \theta = b'$ ab and this angle is clockwise from the auxiliary rays. Also bc is an auxiliary ray drawn from b the position of which is correct. Set off the angle cbc' equal to θ and c' the intersection of the two lines p' c' and bc' is the real plot of C; check by ac'. To find the position of c' geometrically it can be found as follows:—Since the angles ac' x and acx are equal then c and c' are on the circumference of circle passing through the points ac' cx and ac, cx and ax are chords. Find the centre of such a circle and describe it and where it cuts the line p' c' is the true position of C as c'.

161. To find the true position of intersected points.—From the fictitious position c of C let a ray θ' be drawn to a temple, *see* Fig. 68. This ray must first be transferred parallel to c' the true position of C and this can be done by a parallel slide on the sight rule. Let this ray be θ''. From the ray θ'' set off the angle θ clockwise and the ray c' θ will pass through the true position of the temple and its position is found by a true ray from p', intersecting it. The angle θ for correction of intersected points need not be projected by a sector if the artifice is adopted as recommended earlier for placing the table into azimuth.

In reconnaissance work and especially with an army on the line of march this method will be found exceedingly useful, first because cp is not measured and requires no measurement and on p being found and as at c the rays ca cb and cp, are on the table (though p in the first instance was temporary) with the tracing paper method the rays ca cb and cp can be made to fit on a b and the true p and hence the true point c. Rays taken at c can be corrected accordingly, that is shots taken to other peaks, villages, etc., and hence there is no necessity to return to c. In figures 66 and 67 the distance apart of P and C relative to A and B has been shown to be much greater than it will actually be in the field. There would be no loss in accuracy if the distance P to C was $\frac{1}{8}$ the distance A to B as the fixing of P depends solely on the accuracy of the back and forward setting.

This graphical method is practically the same as Colonel Wahab's transfrontier triangulation method where the angles at P and C are measured. Note that the use of the compass is not necessary; it has been suggested here so as to keep the azimuthal error within reasonable bounds

and so that the first intersection of *c* will be more or less correct, thus preventing large shifts in rays for the subsequent adjustment of intersections.

162. Planetabling methods explained. First method.—Having now treated of the theory of finding the position from two, three or more known points by interpolation or resection which in India is known as making a *fixing* or "a fixing" we may proceed with the first method of planetabling that is by magnetic compass and chain for direction and distance respectively. If the country is open, the compass of course can be dispensed with, but where the country is dense probably the method to be illustrated is the only one and has therefore its advantages. Take for instance a wooded valley or hill side where the features are hidden and where there is no certainty as to which stream joins which stream, etc., the only possible way is for the surveyor to "feel his way" through the under-growth and by crossing and recrossing detail to join up stream to stream, path to path. The portion of a map given (Fig. 69) conveys a good idea of such ground and is taken from the 4" forest surveys of Burma. The ground is covered with dense under-growth of bamboo and cane and the surveyor was given the outer boundary as a theodolite traverse. The theodolite traverser left permanent marks 167, etc., for the use of the detail surveyor and also for forest purposes and he traversed in such a way as to give each detail surveyor a line, two to three miles apart, the lines if possible following some recognised administrative boundary or cleared forest fire lines. We will suppose that the dot and barred line was the given traverse and that it enclosed a block. To take this block as it stands and commence the detail survey from one corner and expand on it to the centre, etc., would end in disaster and in all such cases the surveyor must work from the whole to the part and not from the part to the whole, that is he should divide up the large block into smaller planetable traverse blocks.

With this magnetic compass unclamped and his sight rule set on a traverse station either to the back or fore which his table is over a traverse station, he finds his magnetic north and draws a line along the box of his compass. The chainman is sent to chain to a flag in a selected position and a ray is taken to the flag. The surveyor now takes up his table and proceeds to a position beyond the flag and sets up on magnetic north and the chainman chains from the flag to the table. The first measure is plotted along the ray already taken, and thus the position of the flag is known.

Again a ray is taken from the plot of the position of the flag, and the second measure is plotted, this brings him to the position of the table. The surveyor continues in this way across his area following the line of least resistance from theodolite traverse to theodolite traverse. On the map let such a line be represented by AB'A'. It will be found that such a line will have a certain amount of error but this error must remain unadjusted for the present. From B a suitable peg midway let a line B'B be run to meet the theodolite traverse at B.

We now have three lines which can be manipulated and adjusted BB'A, AB'A', and BB'A' and the mean or common point B' can be pricked off, and its position will be as near an estimate of the true position of B' as the circumstances will allow. If the block BB'A is first selected for detail work, some point C in BB' could be selected and a line run to D and closed so that now we have a very much smaller block BCD in which we can proceed to fill in the detail by planetable traverse along the spurs and streams. Whatever error there is in the block BCD is confined to that block, etc. If the map contains sufficient margin of paper, any point may be taken to represent the theodolite traverse station and the traverse run out to the next theodolite traverse station across the blank piece of paper, the whole being traced off on tracing paper and adjusted and pricked through on the table in the true position of the traverse. This system for the main traverses such as AA' and B'B is cleaner and there is only one set of holes and thus no confusion. Any detail, which it has been found impossible to survey, must be shown dotted (*see* map). The contour of such a map is pure eye contouring. In the map the height 940 is given as approximate, that is, it is probably correct to within 10 feet or so. This height has been deduced from flagged trees over traverse heights along the theodolite traverse and height values are entered only here and there in such maps, simply because heights in such ground are not greatly needed and to crowd a map with heights would lead to a wrong impression as to their accuracy.

The tangent clinometer is used to carry forward a system of heights station by station if the ground is fairly open and when this is not possible readings are taken as above noted to flagged trees. The general rise and fall of the ground is put in by angles of elevation and depression and the 0 line of the clinometer is made to sweep along detail opposite, to cut spurs, etc., at the same level approximately as the planetable's position.

It must not be taken for granted that flags are always visible. In dense undergrowth the surveyor will find that cutting a line will be almost

impossible or would delay the work to such an extent as to make the cost of such a survey prohibitive. He will have to locate his direction on the sight rule by the glint of a looking glass, the waving of a branch and sometimes the sound of a drum. To the uninitiated in forest work, such methods will seem crude and exceedingly sketchy and yet these methods have all been used and proved very successful. The beat of a drum with practice can be located to within a yard at 200 feet distance and this on the scale will have no appreciable effect on the ray. Long lengths of cane for measuring have been used on such work as it has been found that the ordinary surveyor's chain gets entangled and comes asunder.

The first setting of the compass is a very important operation and suitable long lines should be selected, and better still, from one traverse across to another. In the map suppose at A′ the planetable was set up and that a tree could be flagged very near A′. Its position being near could be fixed from A′ with an approximate magnetic direction. The planetabler next goes towards B and examines the ground between B and A ; he will probably see the flag fixed at or near A′. He sets up his table to as near his magnetic north as possible over or near a traverse point and he measures and fixes his position. He now sets on A′ or the flag near A′ and thus obtains a very close approximation to the general magnetic north direction of the compass he will require in his work. He rules a line along the compass box edge and continues using this direction throughout his work. The greater the distance between the flag and planetable the more accurate the compass setting.

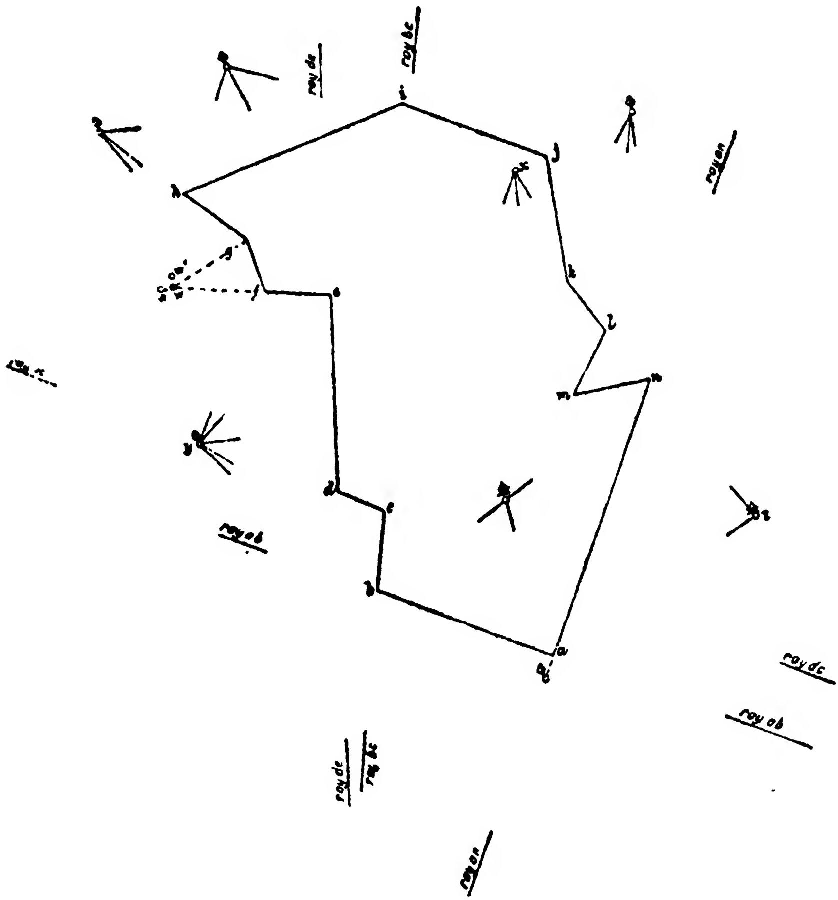
NOTE.—In the map all the theodolite traverse stations along the boundary are not shown but such stations as are permanently fixed on conspicuous points.

163. Second Method.—If the country is open and there is neither a theodolite traverse or triangulation as a basis, a very accurate planetable traverse can be made by chaining with the **back and forward ray system,** *see* Fig. 70. The direction of this traverse is in terms of the initial direction at the starting point and to obtain this a compass is used after which it is no longer required. Such a survey will not be geographically fixed, but will be useful in the mapping of small and outlying blocks of property, areas of grasslands and pasture. The scales vary from 4 to 16 inches to the mile. If carefully done the survey can be made extremely accurate and it is of course less costly than a survey on a theodolite basis. The illustration given will make the system clear.

Let *a* be any point representing a position A on the ground on or near the boundary ; the point to be so placed on the paper as conveniently to take in the area needed.

At A the table is set up and turned into magnetic meridian by means of the compass. The compass is then put away. The flag men are sent along the boundary to B and N and back and forward rays to B and N are taken and the rays produced and labelled as "ray *a n*," etc.

Fig. 70.



If there is a conspicuous back flag or tree near A it should be measured and fixed. The chainmen are set to measure the line A N and while they are thus engaged the planetabler takes rays to conspicuous objects especially selecting such as will be useful to check his traverse later, *e.g.*, *x* *y* and *z*. The table is now removed to N and the position of *n* plotted along the ray *a n* by the measurement given. The plotted position *n* when the board is nearly correct in azimuth should be directly over the flag position

of N. The sight rule is now placed along the ray *a n* and the ray *a n* produced and the point A intersected. The table will be again in azimuth with respect to the initial azimuth at A. The auxiliary points *x y* and *z* and others are again shot to and the chainmen are sent to chain A to B and the table is removed to B and the same procedure gone through. As the positions of B and N have been fixed with reference to initial rays taken at A there should be no error in either B and N or in the points intersected from A B and N. If the points show an error in intersection then there is something wrong and these stations should be revised. The planetabler will thus see the reason for visiting N instead of continuing at once on to B, C, D, etc.

The work is continued to *c d e f*, etc., and as it proceeds the rays taken to *y* for instance should all be passing exactly through the one point. Suppose at *f* or *g* a piece of high ground *w* is visited, that is chained to, and that back and forward rays are taken and the table is set up at *w* and that the conspicuous tree near *a* fails correctly on *w* but a ray taken from *x* falls away from *w* on to *w′*.

This would tend to show that the work is azimuthally correct but that the chainage is incorrect. On the other hand if *x* intersected but the prominent tree forced the ray from *w* to *w″* then the error is an azimuth error and not a chainage error. This check will show the extreme usefulness of intersected points.

By the time the planetabler has reached *i* he will find that the remaining positions of *j k l* and *m* can be fixed by the 3 point problem, and that the chain is no longer necessary. The boundary can now be inked up and the auxiliary points put in and all pencil work rubbed out; the paper cleaned and prepared for the detail work, such detail work being put in by chain and fixing or by intersection.

The following precautions are necessary for accuracy in such work:—(*i*) correct chaining, (*ii*) correct setting (*iii*) a tested sight rule. The accuracy in chaining is understood, as on it depends the distance from point to point. The correct setting is necessary as the board must occupy a position from the back position in exact relation as the flag at the fore position had to the table in the back position, so that on large scales when the table is in azimuth the plotted point should be exactly over the point *in situ*. As regards the sight rule it is essential that the line of sight should be parallel to the fiducial edge of the ruler, and that the sight rule should show no difference for a line drawn one way and then the other, that is,

when the observation vane is one direction and then the rule is turned end for end (*see* para. 146). Inaccuracy in the sight rule enters especially in the back and forward ray work and the surveyor who understands the collimation error in a theodolite will see the reason for this.

Heights for this class of survey are found with the tangent clinometer accepting any datum for A if no given height is forthcoming. The heights of N, B, C, etc., are found by reciprocal observations and height are givens to intersected points and they will check *inter se* the heights of the stations.

The method is quick, useful and very accurate and as much as a seven mile perimeter can be done in a working day.

164. Third method.—The following paragraphs will embody hints instructions and notes on the use of the planetable as a topographer's ideal instrument. Based on a theodolite traverse or triangulated points no other instrument can compete with it as an accurate detail filler for the following reasons:—Any error is confined solely to the fixing from which the work was done and there need be no error as no fixing should be incorrect for reasons given hereafter. The planetable permits of the surveyor at all vantage points checking his own work and if there is, in his detail a disagreement, then either some of his detail is incorrect or his fixing is faulty or at any rate, is not in terms with work from some other fixing. Its facility in finding position by interpolation. Its rapidity in furnishing auxiliary points also intersection of detail. It dispenses with field notes, hence no mistakes in plotting. It delineates the ground as seen by the surveyor who is not expected to trust to his memory and a note book. An inaccessible range can be cut in from three positions. The surveyor is not tied down to a chain though it will be shown that the chain is very often, on certain scales, a very useful adjunct. The scope it gives the surveyor in that it permits him to discriminate between necessary and unnecessary detail with reference to the scale on which he is working. Its disadvantage is possibly its weight and its liability to weather changes when the wood used expands and contracts and the map is distorted so that the plottings of the points become "skewed" and inaccurate

Let it be supposed that a table has been mounted and thoroughly dried. The next operation is the plotting of the points either by rectangular co-ordinates or by latitudes and longitudes. For the former convenient squares should be accurately ruled * and for the latter proper

* A graticule plate is a very quick method for pricking off a rectangle divided into inches.

graticules should be projected and ruled, the ruling being carefully done in blue ink when they have been tested for diagonals, etc. These squares or graticules are extremely useful for planimeter check areas (*see* planimeter, para. 88).

The data given are plotted, checked and inked in circles; the size of circles being proportionate to the accuracy and importance of the given values, *e.g.*, theodolite stations or positions at which the theodolite was set up should have larger circles than theodolite intersected points and again smaller circles to denote planetable intersected points. These circles may be put in carmine.

The planetable is set up as a start on a theodolite station and since, for most small scales the whole planetable in plan is a dot no great accuracy of exact setting over the point *in situ* is necessary. The planetabler puts on his magnetic compass to obtain a rough azimuth and with his sight rule parallel to the plots of the station over which he is standing and another station he examines the line of sight and probably finds the exact alignment by a slight orientation. The compass can now be corrected to a line drawn along its edge or the variation noted, when it is put away. The points, as given, are now thoroughly examined, and if an error is found in a theodolite intersected point of single value, (which has been deduced and given as being possibly correct) the point should, if found to fall off the ray of the sight rule, be refixed with the aid of the planetable. The setting of the table for azimuth must be on the most distant point available for the reason that the setting will be truer. Having recognised and committed to memory the given points, the planetabler should select and cut in all easily recognisable object, such as prominent or curious trees (that is trees of a different colour to the rest or trees with a bare sprig on the top) chimneys, spires, temples, pagodas, and clinometer readings should be taken and written along such rays. The setting should be again checked to see that the table has not moved during these operations. Rays should be drawn with a fine pointed pencil held at an angle with the fiducial edge corresponding to the angle which the pencil makes at the plotted point or position over which the table is set. Where necessary a sketch of the point or object intersected should be made as an aid to memory. Experienced surveyors use very hard pencils which they continually bring to a fine point and have abbreviations such as s, l, g, t. for spur, light, green, tree, h, t, f. for hill, tree, flag and they are capable of drawing a ray and putting a circle on the ray to within a

one quarter inch of the real position. To be able to do this is due to the eye being in time trained to judge distances fairly accurately.

The beginner will have to satisfy himself with long rays and long descriptions and the subsequent rejection of probably more than half of the shots taken, mainly because experience has not taught him that objects conspicuous from one position may be hidden entirely from another. If there were more than one chimney or palm tree situated together they should either all be cut in or left severely alone.

The planetabler has now got so far that he has recognised most, if not all his trigonometrical points and by his most distant setting he has obtained his magnetic direction and has drawn rays to points he requires to supplement the triangulation and he has taken clinometer readings to a number of such. He should now set up at another theodolite station, retest and cut in, but before arriving there it is good plan to set up his table on some conspicuous place not very far from his last and obtain a fixing from which he can shoot in a number of his auxiliary points and obtain very good approximations of their positions. The fixing from which these rays are taken may not be absolutely exact, but it will serve its purpose in so far as it will enable the beginner at any rate to subsequently pick up many points which he might otherwise certainly have confused or lost.

At the second trigonometrical station the planetabler again sets on his most distant point and proceeds to check all the given data and to cut in his own auxiliary points giving them clinometer values.

A third point is visited which need not now necessarily be a theodolite station but may be a theodolite intersected point or if he is sure that he can make certain of several given points and he is within the triangle of such points he might make a fixing. The third set up should be well selected so that the rays to auxiliary points will make good cross intersections with the previous two rays taken. The condition of these rays and the quality of the intersection will determine as to whether the point can be accepted or whether a fourth ray is necessary.

165. It has been noticed that one of the disadvantages of the planetable is its propensity to warp, that is, in a rectangular board owing to the grain of the wood being lengthwise when the contraction and expansion is breadthwise, the points become "skewed" and the following precaution should be deemed necessary. The planetabler should in the first few days cover his area with auxiliary points and visit all his stations

in doing so. If the area, according to the scale, precludes him from doing this it would be better for him to take up only a portion on one table and project and cut in point for the remainder on another board. He will be able to tell whether his points are accordant or not by fixing with one set of points and setting on a distant one and then checking others which are also distant. If the shift is very little the error in the fixing may be inappreciable but with a new board or a board which has yet to settle down to climatic conditions, as much as ¼" contraction in the graticule has been noticed, and it is for this reason that the experienced planetabler will in preference select an old and acclimatised board or table so long as its surface is flat and regular. It is a good system to weather boards in the climate in which they are to be used and in mounting planetables the paper only should be wetted as has been already advised.

This slight digression will, it is hoped, prove to the novice the advisability of first spending a few days going over his ground instead of starting at once on detail work. The question of working from the **whole to part** must be reiterated as it is one of the most important of survey maxims. Further it must not be thought that all boards "give" and points are slewed, and it must not be taken for granted, if trigonometrical or other well fixed points show an error, that the point is wrong and not the fixing.

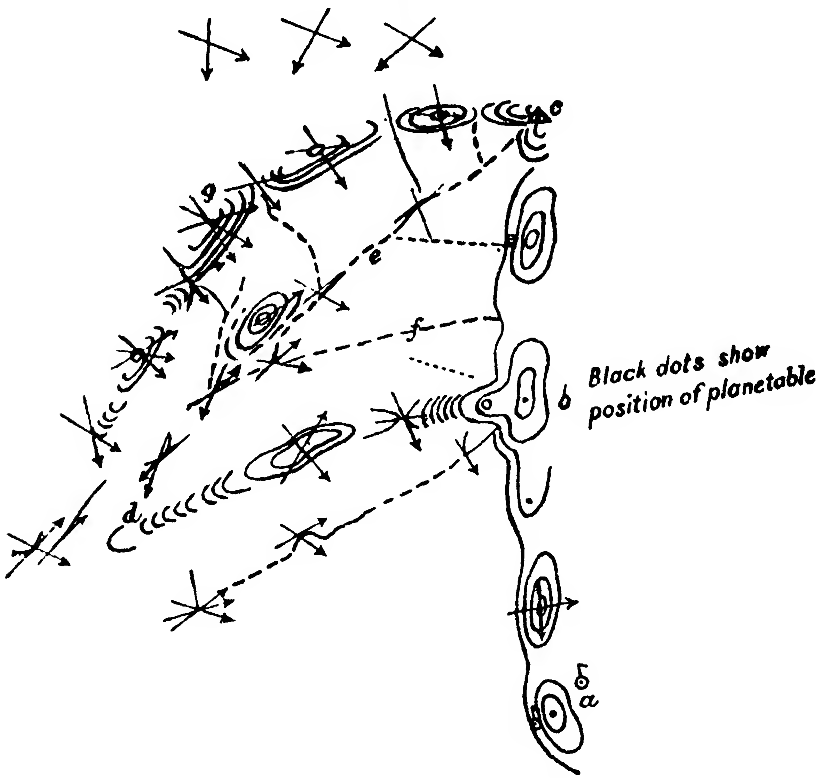
The planetabler must accept his given data without question, that is double value data, and the object of fixing numerous auxiliary data is to avoid any suspicion of doubt and to make the work accord. The planetabler will use his near points to fix by and any contraction or expansion in the map will mean that the error will be evenly distributed and the photography and mapping will correct it when the field work is again drawn and adjusted to true graticules.

Auxiliary points should be thrown out beyond the area of survey to avoid the fixing without the triangle (*see* para. 159) and the planetabler, who rigidly confines himself to points in his area only, will find that any error in his marginal or overlap work is due to his slackness or want of a little extra trouble and foresight.

166. To resume—The table now being complete with data so that the surveyor can fix, that is, see at least three fixed positions in any open clear spot, he should first take up the watershed or highest ground and preferably a high ridge lying between two others and work down to the valleys and spurs. Consider the skeleton survey illustrated (Fig. 71.) Let

a be the first fixing. If the illustration is examined (only one side of the ridge is shown) the rays with arrow heads show what shots were taken—such shots are to hill tops, saddles, spurs, bends and junctions of streams ; heights are read to the most important of these as an aid to contouring. As it is possible that even if *a* is flagged or brushed the point will not be seen down in the valley, and it is quite possible that a fixing will be required in the low ground, on each side two overhanging trees are chosen, brushed, and measured to. These points are shown in small circles. The next position will perhaps be *b* or even an intermediate one (shown by a small cross). At *b* the planetabler fixes up and again takes shots and cuts in and

Fig. 71.



sketches along the ray all streams running directly in a line towards him. At *c* which happens to be a trigonometrical point he continues his cutting in and spends a little time in working out his clinometer heights and so sketches in a few of the hill tops down to the saddles, etc. We will suppose he now finds that although he has the ridge contoured he has only

a small portion of the main stream sketched and that *d* will make a good position for cross intersections and also for a lower and better view up the valley. If he thinks that the chances at *d* are, that he will not see points to fix by he provides for such before visiting *d*.

At *d* he continues work but finds that the portions marked *e* and *f* are still unsurveyed so he goes down into the valley and with the points at his disposal and which he had the foresight to see would be necessary, he fixes and puts incorrectly all the bends and junctions which could not be seen from the high ground. The method of flagging or brushing overhanging trees as a temporary measure is an exceedingly useful one and makes fixing in the low ground easy and this very fact induces the surveyor to fix at or near such detail instead of trusting to cut it in from the surrounding high ground from which it is quite possible some important feature is hidden and omitted. Out crops of rock on the hill side should be cut in, and even if the position of such is slightly inaccurate, the height taken to it would not be so, and such a height would be a great aid to contouring. At *d* having obtained the height of the planetable and the "0" level of the clinometer which could be twisted in all directions and a guide to that level could be marked in as going just at, above or just below a certain bend or junction of a stream. As a test now of the work done the planetable can be taken to *g* and the work examined and the next area to be surveyed shot in etc.; in fact the work as it progresses, should be repeatedly examined when the planetabler has time and this often occurs during the intervals the chainmen are making measurements to flags and edges of cliff, etc. These are golden opportunities and should never be lost. Before quitting a fixing, the surveyor should thoroughly satisfy himself that he has done everything he intended doing and there is nothing left for him to do. One so often sees the planetable lifted and carried 20 yards and returned reset, etc., because it has just struck the surveyor that an important ray which he intended taking has been forgotten. There is no excuse for the surveyor returning time after time to the same fixing or for the surveyor who stands by his table and expects his squad to investigate this, that and the other. This usually means loss of time and consequently money and a great deal of unnecessary shouting. The man who brings in the best work is the man who personally inspects the ground he is surveying leaving nothing to his men to discover, which he himself does not know already. Planetabling demands at the time the whole of the surveyor's intelligence and attention and concentration of the mind is one of quickest and surest ways to get on

with the work. Nothing should be left to chance and everything must be most accurate. To start well is to end well.

167. Hints.—(*a*) In a previous paragraph the rule to fix by your nearest points and set on your most distant has been quoted. The rule is obvious as the closer the cutting in, the less the shift of your point in the triangle of error and the longer the setting the more correct the azimuth will be. It must be recollected that, although three known points will give the fixing, a fourth point should also be intersected to place the fixing beyond any doubt. As regards the fixing without the triangle comment has already been made, but it must be added that surveyors in India will probably planetable thousands of fixings a year without having recourse to a fixing without the triangle and so the avoidance of such a fixing cannot be such a difficult matter.

(*b*) A few additional hints and short cuts will not be out of place here. One frequently hears the expression "a surveyor should not be tied to the end of his chain." Quite so, but the chain as has been remarked, is a useful adjunct and on the larger scales of 16", 8" and 4" to a mile its use has one great advantage, *viz.*, celerity of fixing.

The method of planetabling with the chain in fairly open and flat country is as follows :—Having set up the table and obtained a fixing we will suppose it necessary to descend into a stream say 300 yards distant. While the surveyor is engaged taking rays, etc., the chainmen are chaining a line on any direction which the surveyor has found will bring the chainmen into a suitable position near the stream. The chainmen are directed to halt when they come to the stream and to leave the chain on the ground stretched to the last measure.

As soon as the surveyor has completed his work at the fixing he proceeds to his chainmen. The chain measure, with the ray taken for direction, will give him the position but he will require one other point to orientate his board on. He therefore moves along his chain till he sees a distant point, the further the better, and sets up his table at that position over the chain. He takes off his measure and plots it and sets his board. If his previous ray had been correct and also the measure, and there is no reason why they should not be, he will find no error in the plot, but to make certain it is possible by looking around he will see some other point to test by. If such a point is not at once visible by putting his sight rule on the point over which his table is set and the plot of the other he will probably by the aid of field glasses

see the flag or brush he is searching for. If he had not measured the distance he would not have been able to do this and his search would have been in vain. However let us suppose he obtains no check point at this station but accepts it. He proceeds to put in the detail near him and starts the chainmen in another convenient direction up or down the stream taking a ray on to any good mark such as a tree, rock or bush, and noting that the chainmen are keeping to the line. He follows the chainmaking, for small scales, rough notes of cuttings and off-sets by pacing perhaps, and halts when he thinks he has proceeded far enough and when he can see a point to set on and also a point from which he will obtain a cross ray. This he does by plotting his position on the ray from the last station setting his position on to a distant point and testing by another point. If there is no error the point becomes a fixing from three rays, if there is an error, provided the chaining has been good, it will be small and due to inequalities of the ground and can, if necessary for the scale, be distributed. The advantage of this is that the chain measure enabled the surveyor to set up at a position which he could not have found by interpolation, and further that the chain being dragged up or down the stream permitted him to put in all the bends and other detail from close quarters. Thus the planetable traverse by a distant point for azimuth is a valuable means of saving time; looking for fixings and finding them where they are not always necessary cannot be considered a superior method to the above. It is always advisable to be as near the detail to be surveyed as is possible, and this is very often only practicable by means of this method. To sum up the various advantages they may be said to be as follows:—It is superior to any of the other planetable traverse methods and the plot is found by measure, reduced if necessary, to the horizontal. Even if three points are visible it is a very quick way to find the fixing as the true azimuth of the board is obtained at one setting instead of two or more, and it permits of the table being placed for detail in positions where a fixing would be impossible—its error, if any, can always be checked and distributed by continuing the traverse on to a point where a fixing is possible, and thus closing it, and lastly it is an easy and quick method of putting in a certain class of detail such as a road, path or stream.

(*c*). The next short cut is often employed on transfrontier work, *see* Fig. 72, and is often useful in fixing a point by two intersections only when the rays are acute.

Let a and b be two points on the table from which rays to x have been taken. The position of x may be said to be approximate as regards its distance from a and b, so that if it is possible to plot a and b to a large scale say four times and to intersect x and then to quarter the distance ax or both and to plot this distance from a or b or both, then the position of x will be much more accurate.

Fig. 72.

The expanding of ab to 2, 4 6 or 8 times its distance can be done on any part of the table and a back and forward ray may be the ray ab produced. The point x is intersected from both the true a and b and the expanded a and b. The expanded distance ab may be either so many times the distance between the fixings a and b or better still the chain measure ab plotted to a suitable larger scale

(*d*) Another artifice is as follows:—At some position in which a fixing is required two points can be seen but a third is hidden by a line of trees, a bank or a low range of hills. This frequently happens and the third point is seen only by moving perhaps a 100 yards from the table in a contrary direction to the point from the table, that is the point is visible over the line of trees and the planetable lies between.

First set up the table where two points can be seen and with the magnetic compass obtain, with two rays, an approximate position. Now set the position just found and the plot of the invisible point along the edge of the sight rule. just as if a ray was being taken from the point had it been visible. The sight rule is left in this position and the surveyor takes a flag and from the position at which the required point can be seen, he aligns the flag, sight rule and point and leaves the flag in position. He returns to the table and shoots in the flag from the plot of the third point, draws his ray backwards and thus obtains the third ray. The accuracy of this method depends on the aligning of the flag, sight rule and point and the further the flag is away from the table the greater the accuracy of the ray. The fixing from two inaccessible points has been given in an earlier paragraph (160) and is perhaps of greater use to the reconnaissance surveyor or the intelligence officer attached to a force on the line of march.

168. Contouring.—Rigorous methods will not be touched on in this chapter as the tangent clinometer cannot be considered to be a precise

instrument, but such as it is, it is admirably adapted for the purpose for which it is used, that of obtaining heights to within two feet at a distance of two to three miles and eye contouring by interpolation between such heights. The height of the table is deduced as follows. The clinometer is levelled and say a point is read and the reading on the natural tangent scale is ·012 the distance being scaled is found to be 10,000 feet from the fixing to the point; the difference of height = 10,000 × ·012 = 120 feet to which the correction for curvature and refraction must be applied; a second reading is taken to another point the height of which is known and the mean of the resulting values will be the height of the instrument at the table required from which must be subtracted the height of the instrument above the ground to obtain the value of the ground level.

The rise or fall of ground and its slope can be read and the position of the next contour fixed, and if the slope of the ground is even, additional contours at certain height intervals can be put down by plotting the horizontal distance. A rough rule is as follows:—As degrees and quarter degrees can be read on the left hand side of the vane a fall of 1 foot for $\frac{1}{2}°$ = 114·6 feet horizontal or 115 feet roughly; for 1°, 57·3 feet; for 5°, 11·46 feet, or one-tenth of the distance for $\frac{1}{2}°$.

If the height at the table *in situ* is 1,021 feet and if the contours are at 25 feet interval then with a slope of 5° read to an imaginary plane four feet above the ground the 1,000 feet contour will be (1,021 − 1,000) × 11·46 or 240·6 feet and to obtain the 1,025 foot contour the horizontal distance will be (1,025 − 1,000) × 11·46 = 286·5 feet. If the surveyor has a scale of slopes and the slope is even he can put down from his scale successive contours down the slope.

If two heights are given or found and the surveyor is required to interpolate contours, a simple device for putting down the requisite number at even intervals, is as follows:—Take two pieces of wood joined together by two brackets exactly as for the ivory parallel ruler supplied in instrument boxes. Bore holes at equal and given intervals on the inner edges of the rules and thread them through so that you will have, when the brackets are fully extended, a system of parallel threads at right angles to the rules.

If 20 contours are required between two heights 20 threads are made, by moving the rulers slantwise, to fill up the interval. Each thread is then ticked off (*see* Engineering news, July 30, 1903).

The use of the clinometer to trace out a level line has already been touched upon.

To save a deal of trouble in using the clinometer and when the sight rule with the thread stretched from the vanes is used for very high and low objects, a small circular or an ordinary carpenter's level should be carried for levelment of the table (*see* para. 146). When the table is level or nearly level the clinometer is quickly levelled and the vanes are thus very nearly perpendicular, and hence the heights are nearer the truth.

169. To ensure accurate and high class work in plane-tabling the following cautions should be observed.—(1). If the survey is based on triangulation or traversing with a theodolite the greatest care should be taken to ensure correct plotting from co-ordinate squares which are absolutely accurate.

Large drawing offices have, what is called a graticule plate, which is a hollow square of electrum with prick holes an inch apart along each side. When such a plate is used it is essential to see that the pricker is held perpendicular, that there has been no shift in the plate while pricking and that the fine pencil lines subsequently drawn pass through the points when the pencil is held perpendiculur to the straight edge used.

(2). Having satisfied the conditions above the surveyor should visit at least three of his station marks setting his table in azimuth and testing all the points he can see. The setting should invariably be done on the farthest point available. The lines drawn along the fiducial edge should be without bias, that is to say, if a point does not fall along the ray as correctly drawn, there is something wrong. This can be cleared up subsequently as it is due to inaccurate plotting, the chief cause, or perhaps to an unequal contraction or expansion of the table itself. Having taken rays to all plotted points the surveyor should proceed to fill up gaps by rays to prominent objects where he is sure to require them. The more points fixed in this way, as auxiliaries, the better and quicker the detail work. The rays to objects should be drawn about 2 inches long in the relative position the object appears to be with other points. The tangent clinometer may now be tested against two known heights to make sure that when the correct tangent is read that the bubble is in the centre, if not, correct bubble. Clinometer readings should now be neatly written along the rays taken to objects, to be subsequently worked out in camp when these objects have been fixed by three or more rays.

Another two or more stations are visited with the same objective and further reconnaissance may be done by setting up and fixing from three

known points within the triangle and resecting objects which the surveyor thinks he may lose sight of or forget or possibly not see from any station. He may at such a fixing hoist a flag on a prominent tree near by and measure to it or leave a pole in position. It has been noted before in this work that the author places implicit faith in the dictum that two days spent in this preliminary reconnaissance of fixing extra points with heights is worth a week at the end.

(3). Stations, theodolite intersected points and the planetablers own points should next be inked in circles of blue, of different sizes in proportion to their accuracy, that is, stations, being the basis, come first with the largest circle etc. Heights "top or ground" should be entered, in blue, in neat small figures. The table might now be cleaned of some of the rays no longer required.

No point should be accepted which has not three rays making good intersecting angles at one point. Any station visited which has produced rays giving bad intersections should be revisited and the reason found for any divergence.

(4). The planetabler is now ready for work. He should always work from the higher ground to the lower and whatever piece he accepts for detail he should first examine it for the trend of streams and contours. Actually contours shape the streams but in surveying it is the stream which must be first surveyed and the contour will generally look after itself and can be drawn in irrespective of the actual sight of the ground provided heights exist to guide it. The beginner always attacks the contour and forgets about the stream ; this is wrong.

(5). To survey the streams, such may be cut in from prominent places locating them by resecting bushes, grass etc., on their banks or junctions, but it will be found, till one gets a little expert at this art, that it is much better to **fix over your detail** and follow it up by taking rays along the straight *pieces* and cutting in or measuring small bends and objects on the hump between, to which heights are given, laying the foundation for your system of contouring. If the preliminary work of having sufficient points has been properly done a surveyor should be able to fix almost anywhere in his area and with a good compass, knowing its variation, and especially in India where its variation is fairly constant, a fixing is a matter of a minute only and the survey of a moderately long stream a matter of half an hour with the certainty of having missed no important bend or junction and with clinometric heights at intervals apart

to gauge contours and over and above this a certain amount of skeleton cutting in of extra detail to be filled in on the return journey in the same manner. One cannot be too emphatic about the rule of fixing over detail, that is on the bank of a stream or junction, rather than some distance away. Preparing a large area with flags for intersection etc., often means a confusion of rays, no heights, streams wrong and a hopeless muddle.

(6). The planetabler should make the most of his ground and survey it by small areas or watersheds keeping an eye as he goes from fixing to fixing on objects he has cut in etc.

This is a better way, than taking a mainstream down through the work and returning several days afterwards to pick up rays etc., which had been thrown out as useful helps.

By the watershed method the contouring is knit together and followed through and there is no confusion. As each small area is completed it should be cleaned up and redrawn on the spot so that there can be no doubt as to what is meant, that is, what is a stream, limits of cultivation, etc., as distinct from a contour.

(7). By the above method it will be found that the chain is scarcely ever used except to measure hidden detail. A hundred foot tape is all that would be necessary as fixings for detail would rarely be more than 200 feet apart.

(8). Lastly as the surveyor becomes more expert he should use his clinometer by swinging the zero level to the left and right and notice where the height of his peep sight cuts detail. This is a sure guide as to where the contour at or near his table emerges out of his area to the next and so on.

CHAPTER VII.

CURVES AND ALIGNMENTS.

170. Curves and how designated.—When the direction of an alignment of a road, railway, or canal is required to be changed to another it is usually done by means of a circular arc or simple curve and the original directions or "pieces of straight" become tangents to the arc or curve.

In the United Kingdom a curve is designated by its radius, that is a "15 chain" curve means a curve with a radius of 15 chains and this chain is the Gunter's chain of 100 links or 66 feet. The radius is usually an even number and, as will be seen, this entails a probable angle of deflection which is not some convenient integral part of degrees and minutes. Moreover the radius is never measured or used in laying down the curve and therefore the *Degree* system is preferred and is the system in vogue in America, the Colonies and India.

Technical Paper No. 192 issued by the Railway Board, Simla, lays down that the degree of curvature is measured by the angle subtended at the centre by an arc of 100 feet in length that is the unit of measurement is the radian and an arc of 100 feet with a radius of 5730 feet very nearly (actually 5729·58) subtends an angle of 1° at the centre. This is useful in this way that a 4° curve will have a radius of $\frac{5730}{4}$ feet, etc., and if working with a Gunter's chain and considering it as 100 links and not 66 feet the radius of a 4° curve will be $\frac{5730}{4}$ links.

The circular arc or curve however is not laid out in practice by measurements along the circumference but by chords and thus the usual degree definition is the angle subtended at the centre by a *chord* of 100 feet.

It is perhaps necessary to compare the results by the two systems and show the differences as small compared with the error involved in measuring in the field. For example the radius of a 1° curve is $\frac{100}{\cdot 0175433} =$ 5729·58′ or more accurately 5729·57795′ the logarithm of which is 3·7581226 and a radius of a 12° curve will be $\frac{5729 \cdot 58}{12} = 477 \cdot 46'$ instead of 478·3′ as calculated in a later paragraph. Using both values for calculating

the tangents which are also measured on the lay out (whilst the radius is never) the following values are obtained *viz.*, 774·32′ as against 774·4′ and thus the difference is too small to consider even when a steel tape is used for measuring.

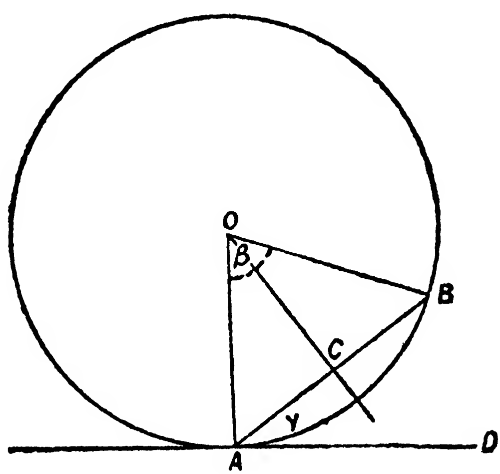
Differences are appreciable for curves of large flexure say 16° on the metre gauge and 48° on the 2′ – 6″ gauge but in such cases the chords are shortened so that the resulting polygon approximates more closely to the arc and the usual practice is as follows:—

For curves 0° to 5° flexure 100′ chords are used.
5° to 10° „ 50′ „ „ „
10° to 20° „ 25′ „ „ „

171. Relation between radius and degree of curvature.—The curve as laid down is the centre line.

By Euclid III. 20 and 32 it can be proved that the angle BOA (fig. 73) is twice the angle BAD. That is the total angle of curvature at the centre (β) is twice the total tangential angle (γ). The angle which a 100 feet chord subtends at the centre is usually designated as (δ) and if in fig. 73 BA = 100′ and BA is bisected in C and OC joined, then :

Fig. 73.



$\frac{100}{2} = \mathrm{R} \sin \frac{\delta}{2}$ or $\mathrm{R} = \frac{50}{\sin \frac{\delta}{2}}$, and thus if the radius is known δ can be found and conversely if δ is known R can be found. Thus we can find the *degree of curvature* in terms of the radius and *vice versa*.

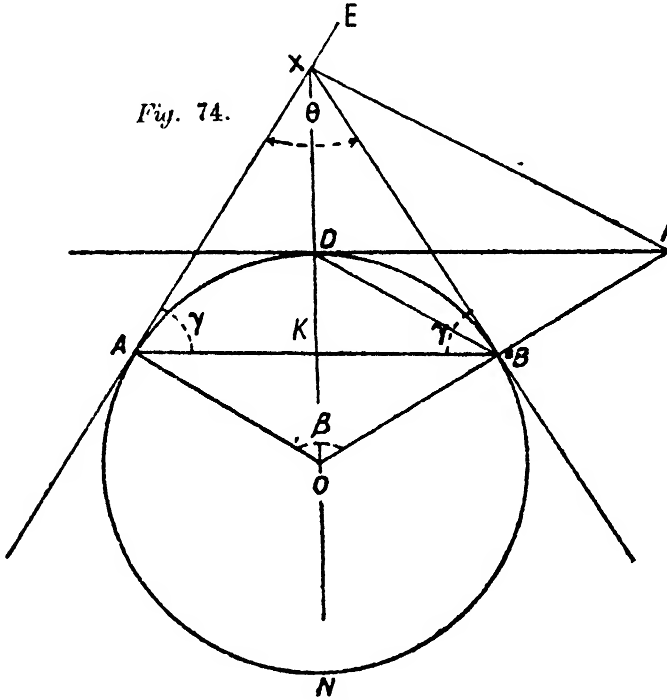
Example.—Find the radius for a 12° curve.

Here $\mathrm{R} = \frac{50}{\sin \frac{12^\circ}{2}} = \frac{50}{\sin 6^\circ} = \frac{50}{\cdot 10453} = 478{\cdot}3$ feet.

172. Relation between degree of curvature and length of tangents (T)—In fig. 74 $\frac{AX}{AO} = \tan\frac{\beta}{2} = \tan\gamma$

and $AO = R \therefore AX = R\tan\gamma$ that is $T = R\tan\gamma$..

Fig. 74.



Example.—Find the length of the tangents for a 2° curve ($\delta = 2°$) containing an angle of 30° – 15′ (β).

$$\text{By formula} \quad T = R\tan\frac{\beta}{2}$$

$$\text{and} \quad R = \frac{50}{\sin\frac{\delta}{2}} = \frac{50}{\sin 1°} = 2864{\cdot}9'$$

$$\therefore \quad T = 2864{\cdot}9 \times \tan\frac{30° - 15'}{2}$$

$$= 2864{\cdot}9 \times {\cdot}27029$$

$$= 774{\cdot}4 \text{ feet.}$$

The figure shows AX and BX, two pieces of straight or tangents, joined by a circular arc ADB and it will be seen that an infinite number of circular arcs can be selected to link the two tangents together depending on T = the distance AX or distance from the intersection points and since θ the intersection angle or $(180 - \beta)$ is a constant therefore the degree of curvature alters to suit T.

It is important to remember that the engineer never measures β the central angle but θ the intersection angle which is $180 - \beta$ which is again equal to the angle EXB.

Having obtained the intersection angle and thus the central angle of his arc he next decides the degree of curvature by selecting the point for the commencement and end of his curve that is he measures T. Having decided T it would be wise for him to see where the vertex D of the curve will fall so that the curve avoids any permanent structure or unsuitable ground. The distance XD is known as the *apex distance* or *external distance* and a peg placed at D on the bisection of the intersection angle serves as a check in running the curve.

173. Apex distance.—The apex distance is equal to R $(\sec \gamma - 1)$ or R $(\operatorname{cosec} \frac{\theta}{2} - 1)$ but a simpler formula is suggested.

In Fig. 74 join DB and through D draw a tangent DF to meet OB produced in F. Join XF.

Then DF is parallel to AB and DF = XB = Tangent, and FB = XD = apex distance therefore XF is parallel to DB, also angle XFD = angle FDB = angle $\frac{\text{DOB}}{2}$ = angle $\frac{\text{AOF}}{4} = \frac{\beta}{4}$

In the right angled triangle XDF, XD = DF tan XFD = DF tan $\frac{\beta}{4}$

$\therefore$ XD or apex distance = T tan $\frac{\beta}{4}$

Another proof is follows :—

$$XD = XO - DO = R \sec \gamma - R$$

$$= R(\sec \gamma - 1) = \frac{R \tan \gamma (\sec \gamma - 1)}{\tan \gamma}$$

$$= T \frac{(\sec \gamma - 1)}{\tan \gamma} = T \frac{\left(\frac{1}{\cos \gamma} - 1\right)}{\frac{\sin \gamma}{\cos \gamma}}$$

$$= T \frac{1 - \cos \gamma}{\sin \gamma} = T \frac{\left(1 - (1 - 2 \sin^2 \frac{\gamma}{2}\right)}{\sin \gamma}$$

$$= T \frac{1 - 1 + 2 \sin^2 \frac{\gamma}{2}}{2 \sin \frac{\gamma}{2} \cos \frac{\gamma}{2}} = T \frac{2 \sin^2 \frac{\gamma}{2}}{2 \sin \frac{\gamma}{2} \cos \frac{\gamma}{2}}$$

$$= T \frac{\sin \frac{\gamma}{2}}{\cos \frac{\gamma}{2}} = T \tan \frac{\gamma}{2} = T \tan \frac{\beta}{4}$$

Example.—Find the apex distance for 2° curve where the central angle = 30°-15′. (*See* Example paragraph 172).

Here apex distance = T tan $\frac{\beta}{4}$ = 774·4 × tan 7°. 34′
= 774·4 × ·1328
= 102·84 feet.

Hence the Engineer would bisect the intersection angle and measure 102·8 feet and fix the vertex peg of his curve where it acts as a check on his lay out both as to direction and distance.

174. The Length of Curve—The Length of curve (L) is measured along the chords. If β = central angle and δ the degree of curvature the $\delta : \beta :: 100 : L$.

$$\therefore L = 100 \frac{\beta}{\delta}$$

Example.—Find the length of the curve in the foregoing example.

$$\text{Here } L = 100 \times \frac{30°\text{·}15}{2°} = 100 \times 15\text{·}225.$$
$$= 1522\text{·}5'.$$

175. Long Chord.—Length of long chord or straight line joining the beginning or commencement of the curve (B.C.) and the end of the curve (E.C.).

$$\text{Here } C = AB = 2\ AK \text{ and } \frac{AK}{R} = \sin\frac{\beta}{2}$$
$$\therefore C = 2\ R \sin\gamma.$$

Example.—Find the long chord for the foregoing example.

$$C = 2\ R \sin\gamma = 2\ R \sin 15°.7\tfrac{1}{2}'.$$
$$= 2 \times 2864\text{·}9 \times \text{·}26093.$$
$$= 1495\text{·}1 \text{ feet.}$$

176. The middle ordinate.—The middle ordinate DK or V

$$DK = DO - KO = R - KO$$
$$= R - R\cos\gamma = R(1 - \cos\gamma)$$
$$\therefore V = R \text{ versin } \gamma$$

or by geometry $AK \times KB = DK \times KN$

$$\therefore DK = \frac{AK \times KB}{KN}$$
$$= \frac{\frac{C}{2} \times \frac{C}{2}}{KN} = \frac{\frac{C^2}{4}}{KN}.$$

Now if DK is very small KN may be taken as equal 2 R

$$\therefore V = \frac{C^2}{8R}\text{(approximately only)}.$$

Example as before—

$$V = R \text{ versin } \gamma = 2864\ 9 \text{ versin } 15°\text{·}7\tfrac{1}{2}'$$
$$= 2864\text{·}9 \times \text{·}03464 = 99\text{·}2'.$$

check $DK + XD = XK$

$$\text{and } \frac{XK}{AX} = \sin\gamma = \sin 15°\ 7\tfrac{1}{2}'$$
$$\therefore XK = A \times S = \sin 15°\ 7\tfrac{1}{2}'$$
$$102\text{·}84 + 99\text{·}2 = 774\text{·}4 \times \text{·}2609257$$
$$202\text{·}04 = 774\text{·}4 \times \text{·}2609$$
$$= 202\text{·}04.$$

In connection with the above it is interesting to note that if a 100′ tape is stretched along the inside edge of a curved rail and a foot rule is used to measure the midordinate, we get

$$R = \frac{15{,}000}{V \text{ inches}} \text{ and if } V = 10'' \text{ then } R = 1500'$$

If however ~~$619\frac{1}{2}$~~ 741·6 inches or ~~$51' \ 7\frac{1}{2}''$~~ 61·8 is taken on the tape, the versin in inches, for such a length, will be very nearly equal to the degree of curvature of the curve since $\delta = \frac{5729 \cdot 58}{R}$.

177. Example on the above formulæ.—Two straight lines, meeting at a known angle θ, are to be joined by a 2° curve. Describe the computations and the method of lining out the curve in 100 feet lengths (I.C.E. 1910).

(*i*). The supplement of the angle θ = central angle $\beta = 180 - \theta$.

(*ii*). $R = \frac{50}{\sin \frac{\delta}{2}} = \frac{50}{\sin 1^\circ} = \frac{50}{\cdot 01745} = 2864{\cdot}9.$

(*iii*). $T = R \tan \gamma = R \tan \frac{\beta}{2} = 2864{\cdot}9 \tan \frac{\beta}{2}.$

(*iv*). $L = \frac{100 \times \beta}{\delta} = \frac{100 \times \beta}{2}.$

(*v*). $C = 2 R \sin \gamma = 2 R \sin \frac{\beta}{2} = 2 \times 2864{\cdot}9 \sin \frac{\beta}{2}.$

(*vi*). Apex distance or external distance $= T \tan \frac{\beta}{4}.$

(*vii*). $V = R \text{ versin } \gamma = 2864{\cdot}9 \sin \frac{\beta}{2}.$

It appears therefore that having made calculations, the Engineer sets up a theodolite on the tangent point and proceeds, by calculated deflection angles and 100 feet chords, to lay out the curve. In practice however such chords have to be dealt with and usually after putting down the 3rd or 4th peg no more can be seen owing to obstacles and the instrument has to be moved forward. The procedure to be adopted will be made clear in the following example which should be closely studied.

178. Setting out a curve with a 100′ chain and a theodolite.—*Example.* Intersection point occurred at station 753 + 34. Angle between tangents was found to be 142°. Put in a 5° curve.

Here δ and θ are given, hence $R = \frac{50}{\sin 2\frac{1}{2}^\circ} = 1{,}146{\cdot}3$ and $T = R \tan \gamma = 1146{\cdot}3 \times \tan 19^\circ = 394{\cdot}7$ (approximate). Chainage at the commencement of the curve or the first T. P. is 394·7 feet back from X the intersection point $= (753 + 34) - (3 + 94{\cdot}7) = 749 + 39{\cdot}3$.

$L = \frac{38^\circ}{5^\circ} \times 100 = 760 \text{ feet} = 7 + 60'.$

Therefore the chainage at the end of the curve = (749 + 39·3) + (7 + 60) = (756 + 99·3) and chainage to the vertex V = (749 + 39·3) + $\frac{(7+60)}{2}$ = (753 + 19·3).

Apex distance = R (sec $\frac{\beta}{2}$ − 1) = 1146·28 (sec 19° − 1). = 66 feet nearly

C = 2 R sin γ = 2 × 1146·28 × sin 19° = 746·38′.

V = R vers 19° = 62·47′.

It is supposed that the surveyor or engineer chained up to the intersection point, registered the value of the chainage, set up his theodolite and after reconnoitring the ground found that the angle between the tangents is 142°. He now either decides the TPs. by the length of the tangent or in this case the curvature (δ) = 5°.

He computes the apex distance to be 66′ to the vertex of the curve which he proceeds to fix by means of a measure of 66′ and the bisection of the intersection angle. He puts in a peg here and labels it vertex with a chainage of 753 + 19·3.

His work at the intersection point is completed and he proceeds to measure 394·7′ along the tangents and fixes pegs to denote the TPs. or commencement and end of his curve. The chainage at the commencement of the curve will be 749 + 39·3 and the chainage at the end of the curve will be 756 + 99·3.

The theodolite is now centered over the first T. P. peg at chainage 749 + 39·3. The instrument is levelled and the plates set to 0° 0′ 0″; the lower plate is now unclamped and the telescope set on the intersection point and the lower plate clamped when the peg is intersected. The upper plate is now released and the following checks made to ensure of the initial work being correct. The vertex peg should read an angle of 9°·30′ $\left(\frac{\gamma}{2}\right)$ and the other T. P. peg should read 19° (γ). This is assuming that the curve is a right handed one; if a left handed one these values should be subtracted from 360°.

These checks having been made the curve can be proceeded with and the pegs marking the different stations on the curve will mark the *centre line* of the track or canal, etc.

In order to obtain the 750th peg which is 60·7′ distant from the position of the theodolite the tape or chain is stretched to 60·7′ in a direction which on the theodolite (A vernier usually) will read 1° ·31′ ·0″. This is found as follows:—Since the degree of curvature is 5° the tangential angle for each 100′ = 2° ·30′.

∴ the tangential angle for 60·7′ = $\frac{60\cdot7}{100}$ × $2\frac{1}{2}$° = 1° 31′·03″. The 751st peg will be put in with an angle of 1° ·31′ + 2° 30′ = 4° ·01′ and the chain

or tape stretched 100′ from the 750th peg into this line and so on. In using a chain with the tape they must be compared against each other. The chain again is not necessarily correct throughout its whole length if its total length is correct (*see* paragraph 20). The curve will be checked at the vertex by a distance of 19·3′ from the 753rd peg with an angle of 9° 30′ and the last peg should measure 99·3′ from the 756th peg with an angle of 19°.

The tabular statement and field book [Plate XV (*a*)] will show how the record should be kept.

Supposing for some reason not more than 300′ can be seen from the theodolite and the instrument has to be moved, then the pegs over which the theodolite would be set, *see* fig. 75, are stations 749 + 39·3, 752, 755 and 756 + 99·3 the last peg, to check the curve and lay out the tangent or straight.

The pegs and distances will remain as before but the angles will alter for this reason that at pegs 752 and 755 the direction of a new tangent will have to be found.

The procedure is as follows :—Peg 752 is fixed as before at reading 6°·31′ the lower plate of the theodolite up to now remaining clamped.

On setting up the theodolite at peg 752 the upper plate is found set at reading 6°·31′ the lower plate is then unclamped and the telescope pointed to peg 749 + 39·3 when the lower plate is clamped on the intersection and thus the instrument will be reading 6°·31′. Next unclamp the upper plate and double the reading or make it 13°·02′ and the telescope will be pointing

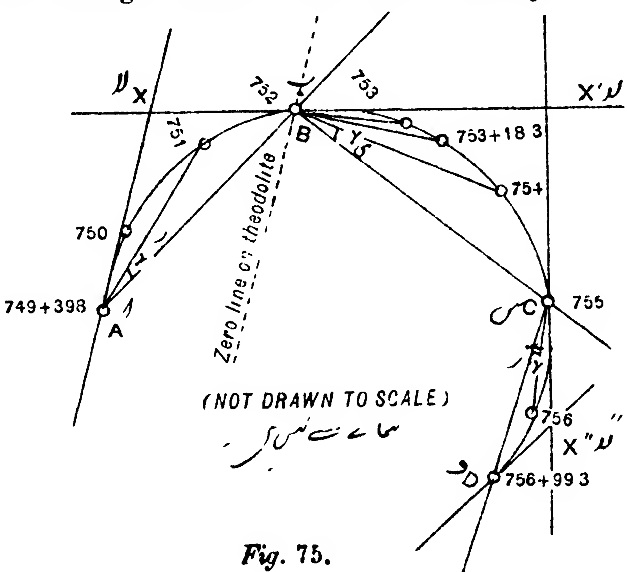
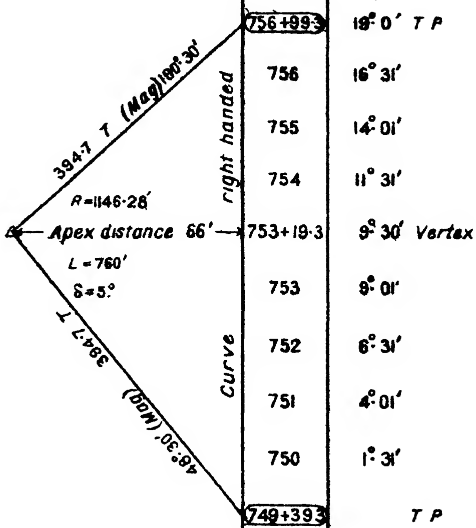


Fig. 75.

along the tangent to the curve at this point but in a backward direction

Specimen of field book

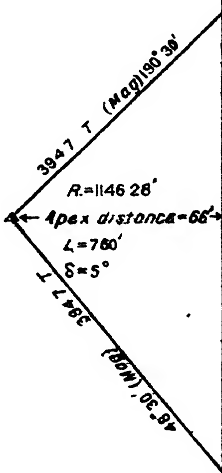
Plate XI a.



	Stations	Distance	Tangential angle as calculated	Tangential angle as used
T P	749+39·3			
	750	60·7	1° · 31′ · 03″	1° · 31′ · 00″
	751	100	2 · 30 · 00	4 · 01 · 00
	752	100	2 · 30 · 00	6 · 31 · 00
	753	100	2 · 30 · 00	9 · 01 · 00
Vertex	753+19·3	19·3	0 · 28 · 57	9 · 30 · 00
	754	80·7	2 · 01 · 00	11 · 31 · 00
	755	100	2 · 30 · 00	14 · 01 · 00
	756	100	2 · 30 · 00	16 · 31 · 00
T.P.	756+99·3	99·3	2 · 28 · 57	9 · 0 · 0

Plate XI b.

Specimen of field book



756+99.3	30°01'	T.P.
756	30°32'	
755	200°32'	
754	198°02'	
753+19.3	196°01'	Vertex
753	195°32'	
752	6°31'	
751	4°01'	
750	1°31'	
749+39.3		T.P

Tabular Statement

Stations	Distance feet	Tangential angle as calculated	Tangential angle as used	Index angle	Remarks.
T P 749+39.3					
750	80 7	1°.31' 03"	1°.31 00"	1°.31'.00"	
751	100	2.30.00	2.30.00	4.01.00	$\gamma' = 6°\ 31'\ 00"$
752	100	2.30.00	2.30.00	6.31.00	
753	100	2.30.00	2.30.00	195.32.00	
V. 753+19.3	19 3	28 57	29.00	196.01.00	$\gamma'' = 7°\ 30'\ 00"$
754	80 7	2.01.03	2.01.00	198 02.00	
755	100'	2.30.00	2.30.00	200.32 00	
756	100'	2.30.00	2.30.00	38.32 00	$\gamma''' = 4°\ 59'\ 00"$
T.P 756+99.3	99.3	2.28.57	2.29.00	33.01 00	
					$2(\gamma' + \gamma'' + \gamma''') = 38°$
				218. 0.00	is the direction of the straight
			or	38. 0.00	

If the curve is left handed then the readings on the theodolite will be anti clockwise from 360° so the angles will be Subtracted from 360° &c

that is the angle XBA, fig. 75 has been made equal to the angle XAB so that BX is a tangent to the curve at B. Add 180° to the reading 13°·02′ and direction BX′ will be found so that the direction of the required tangent will be in the line of the telescope when the reading on the theodolite is 193°·02′ or 13°·02′ + 180°. The instrument could have been transitted or face changed so as to avoid the 180° but this is inadvisable as any collimation error in the instrument is transferred to the line B X′.

The reading of the 753rd peg will be 195°·32′ or 193°·02′ + 2°·30′ and so on, and the reading of the 755th peg will be 193°·02′ + 7°·30′ = 200°·32′.

The theodolite has again to be removed to peg 755. Set up the instrument at peg 755 and unclamp the lower plate without interfering with the reading 200°·32′ of the upper plate and set the telescope to read peg 752.

Now the angle CBX′ is 7° 30′ and so that the angle BCX′ be also 7°·30′ the reading of the instrument when the telescope is pointing in a direction CX′ will be 208°·02′. CX′ is a tangent to the curve at C. Again add 180° to the reading of CX′ and the direction of the required tangent at C is found which will be at reading 28°·02′. The 756th peg is put in with the theodolite reading 28°·02′ + 2°·30′ = 30°32′ and the last peg is put in with the theodolite reading 28°·02′ + 2°·30′ + 2°·29′ = 33°·01′.

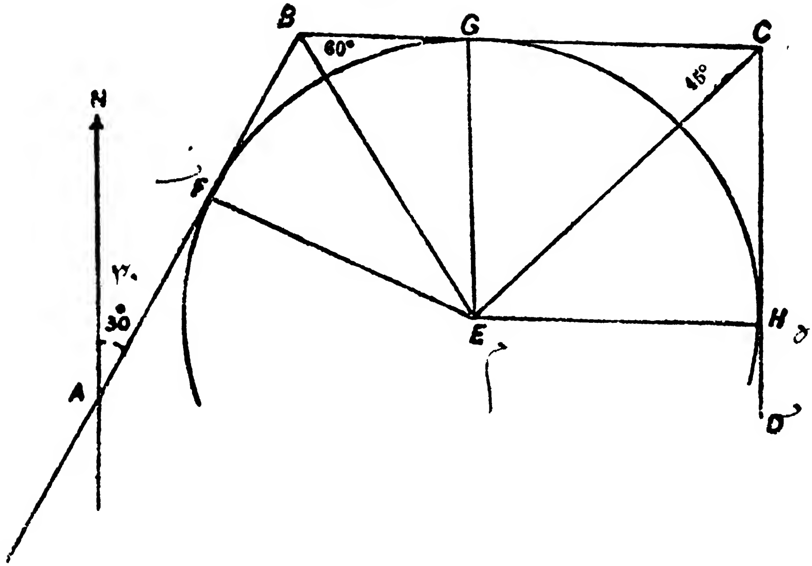
To obtain the direction of the straight the instrument is moved finally to the T. P. on peg 756 + 99·3 clamped at a reading of 33°·01′. Peg 755 is again intersected at 33°·01′ by unclamping the lower plate and reclamping on the intersection peg 755. The value of the angle DCX″ is added by releasing the upper plate and clamping it again at reading 33° ·01′ + 4°·59′ = 38°. Add 180° and the telescope will be pointing down the straight at reading 218°. At every even station, that is 2nd, 4th, 6th, etc., there will be this difference of 180° which after all is not inconvenient and to avoid it, would mean bringing in any collimation error there is in the instrument. The field book and tabular statement are given in Plate XV (*b*).

If the curve is left handed then the readings on the theodolite will be anti-clockwise from 360° so the angles will be subtracted from 360°, etc.

179. Problem.—A light railway is to be carried round the shoulder of a hill and its centre line is to be tangent to each of the three lines AB, BC, and CD as follows:—AB, bearing 30°, BC, bearing 90°, length 600 feet and CD bearing 180°. Calculate the radius of the curve and the length required for setting out the tangent points (U. of Lon.)

To obtain the common centre E, bisect the angle ABC and the angle

Fig. 76.



BCD and produce their bisectors to meet in E. From E draw EF, EG, and EH perpendicular respectively to AB, BC, and CD.

Now EF = EG = EH = the radius of the required curve. BF = BG = tangents for first portion of curve and CG = CH = tangents for second portion of curve.

Let radius = R.

Now angle EBG = 60° + EG = R ∴ $BG = \frac{R}{\sqrt{3}} = \frac{R\sqrt{3}}{R}$

Again angle GCE = 45° + EG = R ∴ GC = R

Then from data $\frac{R\sqrt{3}}{3} + R = 600$

$$\therefore \frac{R\sqrt{(3+3)}}{3} = 600$$

$$\therefore R = \frac{1800}{\sqrt{3}+3} = \frac{1800(3-\sqrt{3})}{6}.$$

$$= 300\ (3 - \sqrt{3}) = 300 \times 1{\cdot}2679.$$

$$= 380{\cdot}37 \ldots\ldots\ldots\ldots (i).$$

$$BG = \frac{R\sqrt{3}}{3} = 300\frac{(3-\sqrt{3})\times\sqrt{3}}{3} = 100\,(3\sqrt{3}-3) = 100 \times 2\,19615.$$

$$= 219{\cdot}61 \ldots\ldots\ldots\ldots (ii).$$

and $GC = R = 380{\cdot}37 \ldots\ldots\ldots\ldots (iii).$

180 By offsets from the chords produced.—In Fig. 77 O is the centre of the arc ABC and A*b* a tangent at A. AB is a chord subtending a central angle AOB.

If A*b* be made equal to AB then angle AOB = twice angle BA*b*.

If AB is bisected at P and OP joined then the triangles AOP and AB*b* are similar such that $\frac{Bb}{AB} = \frac{AP}{AO}$.

Now B*b* may be considered the offset from the tangent and thus

$$Bb = \text{offset} = \frac{AP \times AB}{AO} = \frac{\frac{c}{2} \times c}{R}$$

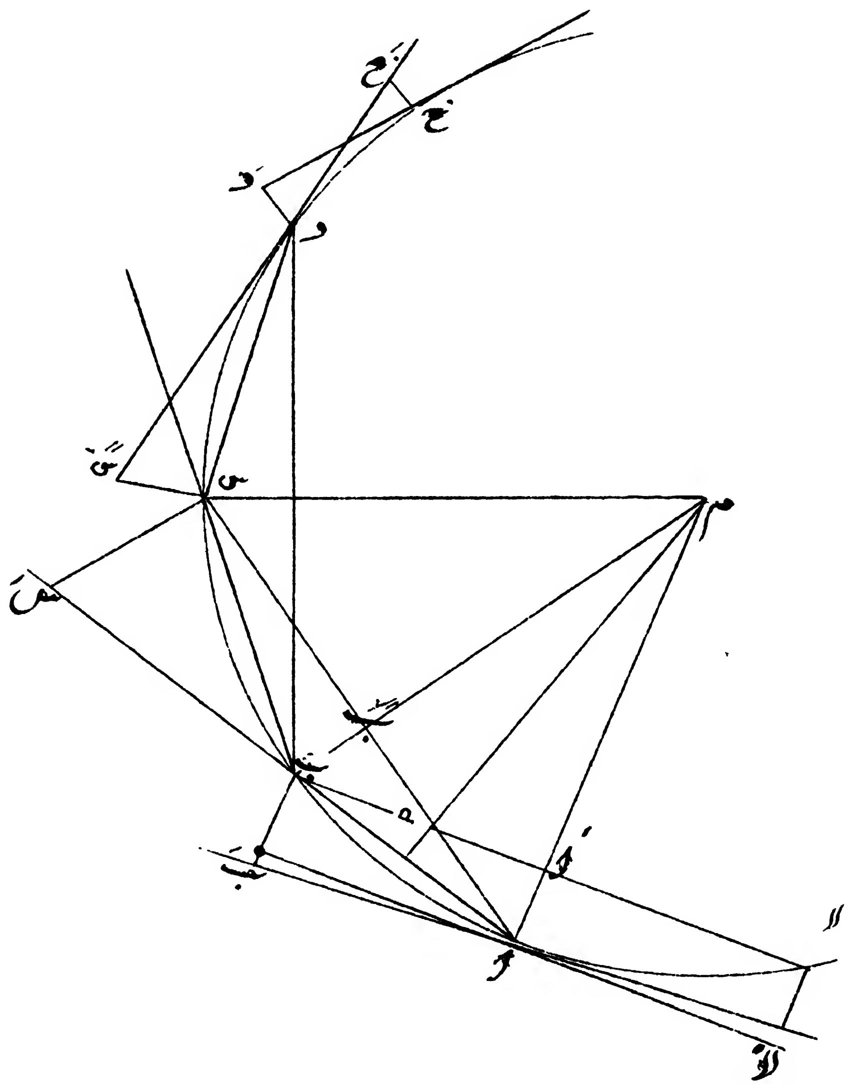
$$= \frac{c^2}{2R} \text{ where AB a chord is equal to } c.$$

Similarly if AB is produced to *c* and B*c* and BC made equal to AB, then the offset from the chord AB produced $= Cc = \frac{\text{chord}^2}{R} = \frac{c^2}{R}$.

B*b* is known as the ***tangential*** offset and C*c* the ***deflection*** offset.

The distance AB on the chord is usually 100′ or 100 links with offsets calculated in the same terms of feet or links. The laying out is simple and results accurate; the layout becomes complicated only when sub-chords are considered.

Fig. 77.



The first bB is usually put down considering AbB as a right angle. Subsequent chord offsets should be pegged so that the resulting triangle say BcC is isosceles.

The alignment for producing chords is best done with a string and sighting by means of chain arrows.

By chords and offsets ending with a sub-chord.

Example.—The intersection angle between two tangents is found to be 169°. A 6° curve has been considered suitable. To lay down the curve with 50′ chords.

Here $\delta = 6^\circ \therefore R = \frac{5730}{6} = 955'$

and $180 - \theta = 180 - 169^\circ = 11^\circ = \beta$

$$L = \frac{100 \times \beta}{\delta} = \frac{100 \times 11}{6} = \frac{1100}{6} \times 183{\cdot}3'$$

The curve will thus consist of 3 chords of 50′ each and one sub-chord of 33·3 at the end.

If xAb is the tangent where $xA = Ab = 50'$; Xx and Bb are tangential offsets $= \frac{c^2}{2\,R} = \frac{50 \times 50}{2 \times \cancel{995}\ 955} = 1{\cdot}31'$ or since the angle $BAb = \frac{\delta^\circ}{2} = \frac{3}{2}^\circ$ $\therefore$ $Bb = 50 \sin \frac{3}{2}^\circ = 50 \times {\cdot}02618$. Lay off xX ~~=~~ or $bB = 1{\cdot}31'$ and join AB then B will be a chord of the arc and B will be the first peg 50′ from A. Join AB by a string and produce the alignment to c 100′ from A and then with a 100′ tape with ends at c and C and passed round the peg or chain arrow at B the 50′ mark touching the arrow at B and with an offset rod measure $c\,C = \frac{\text{chord}^2}{R} = \frac{50 \times 50}{995} = 2{\cdot}62'$. C will be the next point on the curve. The peg at D is put in by the same isosceles triangle method with the tape and offset rod.

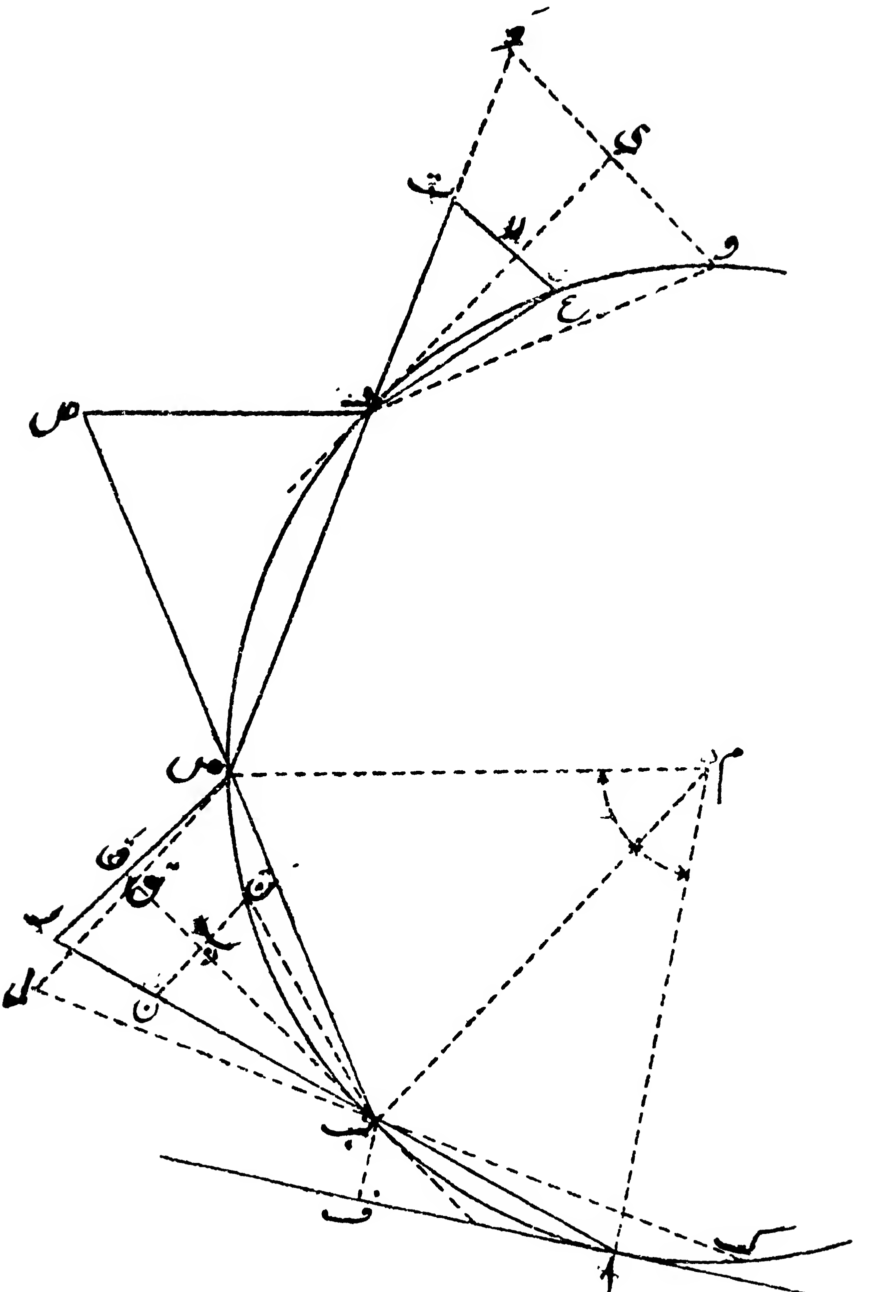
It is next required to find E the end of the curve 33·3′ from D and at E to prove the tangent direction.

The reverse of the setting out method is employed that is instead of finding the curve from the tangent, the tangent at D is found by laying off $Cc' =$ *tangential offset* for $50' = 1{\cdot}31$ when $c'D$ is the tangent at D.

Produce $c'D$ 33·3′ to e and lay off $eE = \frac{(33{\cdot}3)^2}{2\,R} = {\cdot}58'$. E is the end of the curve and to find or prove the tangent set off an offset $Dd = Ee = {\cdot}58'$ and join dE and produce it and it should coincide with the original tangent if the work has been correctly done.

181. Starting with a sub-chord.—Had station A been given as peg No. 181 + 22 the Ab would have been measured as 28 feet and

Fig. 78. شكل ٨



Ax as 22 feet and the offsets Bb would have been equal to $\frac{28 \times 28}{2\,R}$ and $Xx = \frac{22 \times 22}{2\,R}$ that is that the curve would have started with a sub-chord.

This method, to the exclusion of all others, is recommended as there is less calculation and no confusion in the field and it is helpful in understanding the method of laying down a curve by offsets inside the curve. For sharper curves chords of 25 feet may be employed.

182. Additional method.—In curves laid out by chords and offsets from the chords produced it is a simple matter to get the offsets required if the curve starts and ends with full chords for in that case the tangential offset is $\frac{c^2}{2\,R}$ and all the other offsets are $\frac{c^2}{R}$ [In laying out curves without the aid of a Theodolite it is usual to use chords of 25 feet or less.]

If, the curve starts and ends with sub-chords, that is, a chord shorter in length than the full chord we intend using, we have to use other formulæ for the offsets. In Fig. 78 AB is the first sub-chord and BR is the sub-chord produced to R to the length of a full chord, the offset RC is what we require. Had the first chord been a full chord such as KB and it was produced to L the offset LC would have been $\frac{c^2}{R}$ where C = full chord.

Now to find RC we have $RC = RQ' + Q'C$ and $Q'C = QC$ (approx.)

$\therefore Q'C = \frac{c^2}{2\,R}$ (approx.) where C = full chord and BQQ' is a tangent.

Again $MP = \frac{s^2}{2\,R}$ where s = sub-chord and approximately

$$MP : MB :: RQ' : RB$$

$$i.e.\ \frac{s^2}{2\,R} : s :: RQ' : C$$

$$\therefore RQ' = \frac{C \times s^2}{2\,R \times s} = \frac{C \times s}{2\,R}$$

$$\therefore RQ' + Q'C = \frac{C \times s}{2\,R} + \frac{c^2}{2\,R}$$

$$\therefore RC = \frac{C}{2\,R}(s + C)$$

The offset SD will be $\frac{c^2}{R}$. If a sub-chord ends the curve it may similarly be shown that TE or offset from previous long chord produced $= \frac{s_e}{2R}(C + s_e)$

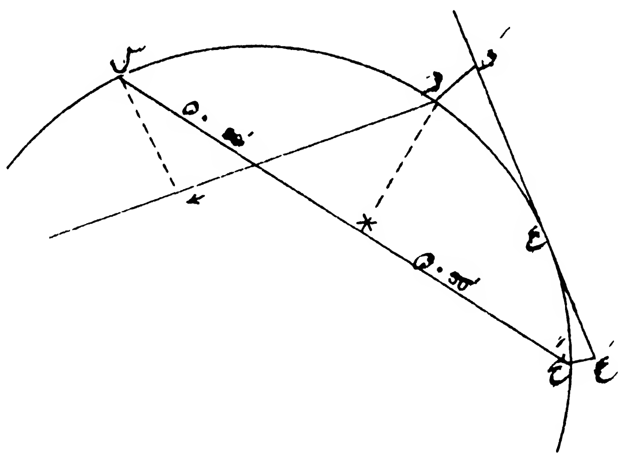
Where s_e = sub-chord at end and C = full chord.

This system of curve ranging is useful in confined areas but it must be understood that a slight error in the layout increases as the square of the distance from the incorrect point.

183. By offsets inside the curve.—This method is employed where it is found that obstructions exist without the curve, such as buildings, walls, fencing, etc. If the example in para. 180 is taken and a reference made to Fig. 77 the tangential offsets bB and xX are laid down in the same manner 50′ from A in either direction. XB is a chord of the arc and is 100′ long very nearly and Aa is the versin of half the angle BOX × R = R versin $\frac{6^\circ}{2}$ = R versin 3° = 995 × ·00137 = 1·36′.

Therefore from B lay off Bb' 1·36′ towards O join Ab' and produce it 50′ to C or in practice lay down the 100′ tape from A to C and at 50′ mark let Bb be 1·36′ from peg B. C is 100′ along the curve from A and so on. There remains the sub-chord of 33·3 from D.

Fig. 79.

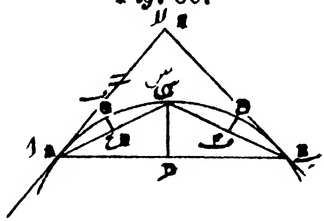


This again is not a difficult matter if the previous method has been thoroughly understood.

In fig 79 D is 150′ from A along the curve and it is required to find the point E at the end of the curve and the direction of the tangent. Continue the curve to E′ by the usual method so that E′ is the whole number peg 200′ from A along the curve. At D lay off a tangential offset Dd = $\frac{\text{chord}^2}{2R} = \frac{(33{\cdot}3)^2}{2 \times 995}$ = ·58′ and at E′ lay off a tangential offset E′e = $\frac{(16{\cdot}7)^2}{2R}$ = $\frac{(16{\cdot}7)^2}{2 \times 995}$ = ·15′ measure d E = 33·3 feet and this is E the end of the curve and d E e' is the tangent.

184.—The versin method.—Closely allied to the above method is the versin method the calculations of which are simple and the methods of lay out are easily followed by an ordinary workman with this advantage that in a sharp curve the greater the number of supplementary chords and offset the greater the number of points on the curve.

Fig. 80.



Let the points A and B (fig. 80) represent the TPs of the curve and since the direction of the tangents is known the angle XAB or γ is known. Measure the long chord $C = AB$ and since $AB = 2R \sin \gamma$ $\therefore$ R is known and hence DC or $V = R$ versin γ is known.

To lay down the curve measure the distance AB bisect it in D and erect the midordinate $DC = R$ versin γ. C will represent the vertex of the curve. Again join AC and BC and bisect them and erect ordinates EG and $FH = R$ versin $\frac{\gamma}{2}$ and so on till sufficient points are found to set down the curve.

There is no point in giving further methods of lay out of simple curves such as by *ordinates from the long chord*, *offsets from the tangent* as all these cases are met with in a simple way in the methods recommended.

The method of laying out a curve with two theodolites is a practice scarcely to be met with in India and it is doubtful whether it is ever really practicable except in a flat treeless plain and with a special signalling code between the instrument men and flag holders. It is therefore omitted.

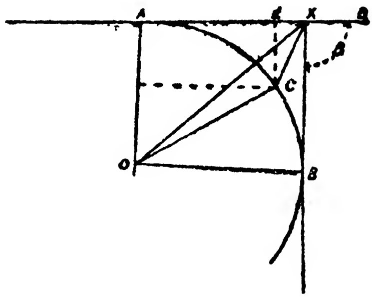
185. Problems.—The following problems in curve ranging are useful to know and are therefore given.

It sometimes happens that having been given the tangents it is required to know what curvature might be given so that the curve will pass through some certain point on the ground that is AX and BX are given and the angle β. (*See* fig. 81). Find a curve which shall pass through the point C and join the two tangents.

Let $\beta = 14°$ and with the theodolite at X let the angle AXC measure 130° and XC measure 44′. It is required to find a suitable curve which will join AX and BX and pass through the point C.

Join OX and OC and through C draw CE at right angles to AX.

Fig. 81



The angle AXB $= 166°$ and hence angle BXO $= \frac{166}{2} = 83° =$ Angle AXO; and angle OXC $= 130° - 83° = 47°$.

$$\text{Now } \frac{OA}{XO} = \sin 83° \therefore XO = \frac{R}{\sin 83°}.$$

In the triangle XOC XO : OC :: sin XCO : sin 47°.

$$\therefore \sin XCO = \frac{XO \sin 47°}{R} = \frac{R}{\sin 83°} \times \frac{\sin 47°}{R}$$

$$= \frac{\sin 47°}{\sin 83°} \therefore XCO = 132°\cdot 32'$$

and since the angle OXC $= 47°$ and XCO $= 132°\cdot 32'$.

$\therefore$ the angle XOC = 28 mins.

Again the angle AOC = angle AOX + angle XOC $= 7°\cdot 28'$

and R vers AOC = EC and EC = CX sin AXC.

$\therefore$ R vers AOC = CX sin AXC.

= 44 feet $\times$ sin 130°.

$$\therefore R = \frac{44 \times \sin 130°}{\text{versin } 7°\ 28'} = 3975'$$

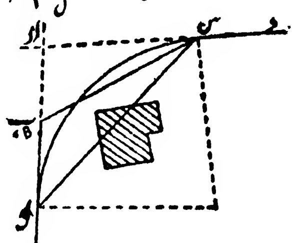
$$\text{and } R = \frac{50}{\sin \frac{\delta}{2}} \therefore \sin \frac{\delta}{2} = 0{\cdot}01251 \text{ or } \delta = 1°\cdot 26'\cdot 24''.$$

Now half central angle $= \gamma = 7°$ and T = R tan γ.

therefore AX and BX are 488′ from X.

186. Problem When the intersection point is not visible.—Let AB and DC be the direction of the two tangents and let B and C be intervisible. It is required to join AB to CD by a suitable curve (Fig. 82).

٨٢ شكل *Fig.* 82.



Procedure.—Measure the line BC also the angles ABC and BCD.

The intersection angle between the tangents will be equal to angle

ABC + angle BCD − 180° and $\gamma = \frac{360° - \text{angle ABC} - \text{angle BCD}}{2}$

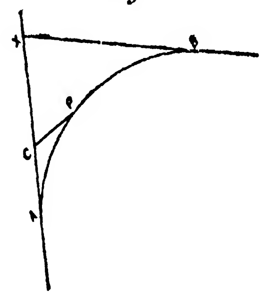
$$\text{Now XB} = \frac{\text{BC sin XCB}}{\text{sin BXC}} \text{ and XC} = \frac{\text{BC sin XBC}}{\text{sin BXC}}$$

∴ XB and XC are found and since XC = XB + AB. ∴ AB is known and can be measured back along the tangent from B and thus A and C need not also be intervisible.

also XC = R tan γ ∴ R is known, etc.

187. To find a certain point on the curve.—It sometimes happens that a certain point or points on the curve such as a 1,000 foot peg is required to be fixed on a curve or there is (*see* fig. 83) say an obstacle between A and P and the work up to P requires checking before proceeding on to B; the point P can be fixed as follows:—

Fig. 83.



Let δ = 2° and β = 40° and chainage at T C = 10159. It is required to fix for check purposes the peg at chainage 11000 at P.

Now L = A P = 110·00′ − 101·59′ = 841′

The central angle subtended by A P will be 8·41 × 2° = 16° ·49′ ·12

and if C P is a tangent at P then C P = C A = $\frac{5729·58}{2}$ × tan 8° 24′ ·36″ = 423·55′.

Therefore P can be fixed by measuring 423·55′. to C along A X and at C an angle of 16° ·49′ ·12″ is set off which is the angle X C P and C P is measured 423·55′ to P.

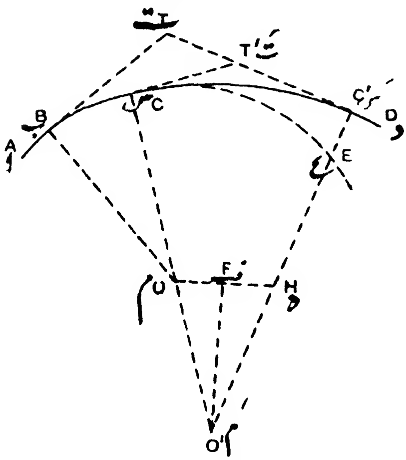
Now C P is a tangent to the curve at P and if the theodolite is being used the direction P C at P can be utilised for laying out the next portion of the curve since it is supposed that an obstacle such as a high bank or jungle exists which intercepts the direction P A.

188. Compound curves.—The following are only the geometric solutions to make calculations by. The curves are actually laid as previously described. A compound curve may consist of two, three or more portions of arcs of different radii and is adopted where the line is required to pass through given points to avoid obstructions, or where a principal station or terminus is required.

189. To find the radius of the second curve, the two tangents, the starting point and one radius being given.—In fig. 84 from the given point B in the tangent AT, draw the given radius BO perpendicular to AB; and draw the curve to some point C, where it is found convenient to change the radius; draw the radius OC, and perpendicular thereto draw CT′, meeting the tangent DT in T′; make

T′ C′ = T′ C′ and from C′ draw C′ O′ at right angles to TC′ meeting CO, prolonged if necessary, in O′; then O′ is the centre of the arc CC′ of the curve, conformably to the nature of tangents.

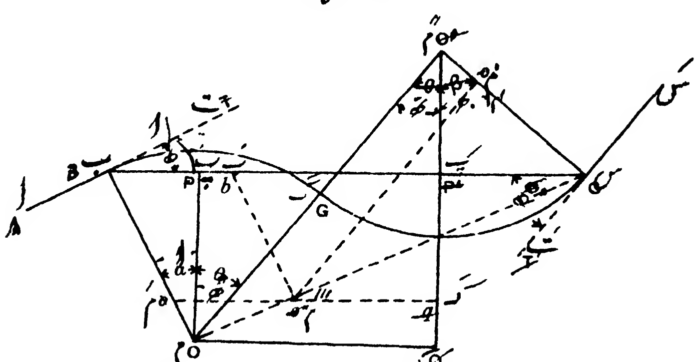
Fig. 84.



190. One of the two radii of the compound curve, and its starting and closing points being given, to find the other radius.—Let AB, C′D (fig. 84) be the tangents, B and C′ the starting and closing points of the curve. Draw the lines BO, C′H each = given radius and perpendicular to the tangents; join OH, and bisect it in F; draw O′F perpendicular to OH, meeting C′H prolonged in O′; join OO′ and prolong it till OC = C′H; then the points O,O′, are the centres of the arcs BC, CC′, which constitute the curve O′C = O′C′ being the radius required.

191. When the two portions have the same radius, to determine that radius, the tangential points and their distance apart being given—In fig. 85 let AB, CD be the tangents, B and C the given tangential points, and BC the given distance, draw *Bo*=*Co′* respectively, perpendicular to AB, CD and of any convenient length; through *O*, parallel to BC, draw *oq* indefinitely, with the compasses apply *o′ o′* = 2*Co′* = 2B*o* cutting *oq* in *o″*;

Fig. 85.



through C, draw *Co″*O, meeting B*o* prolonged in O, and through O, parallel to *o″ o′*, draw OO′ meeting *Co′* prolonged in O′; then O, O′

are the centres, and OB and O′C are the equal radii of the serpentine curve BGC; the common normal of the portions BG and GC of the curve being $OGO' = 2BO = 2CO'$.

Draw OP and O′P′ perpendicular to BC and OQ parallel to BC.

Trigonometrical Solution of Case III.—If $\left.\begin{array}{r} OB = OC' = r \\ TBC = \alpha, BTC' = \beta \\ POO' = OO'Q = \theta \end{array}\right\}$

Then $BP + PP' + P'C = BC$, or, $r \sin \alpha + 2r \sin \theta + r \sin \beta = BC$, (1)

Again, $OO' = 2r$, or, $\frac{OP}{\cos \theta} + \frac{O'P'}{\cos \theta} = \frac{r(\cos \alpha + \cos \beta)}{\cos \theta} = 2r.$

$\therefore \cos \alpha + \cos \beta = 2 \cos \theta$..................................(2)

Hence, r and θ are known.

Example.—Given two tangents AB and CD not parallel and B and C the starting and ending points on the S curve and BC the distance between. Find the common radii if $\alpha = 15°$ $\beta = 20°$ and $BC = 1500'$.

By formula—$\cos \alpha + \cos \beta = 2 \cos \theta$

$\therefore \frac{\cos 15° + \cos 20°}{2} = \cos \theta.$

$\cdot 9528092 = \cos \theta \therefore \theta = 72° \cdot 20'$ very nearly.

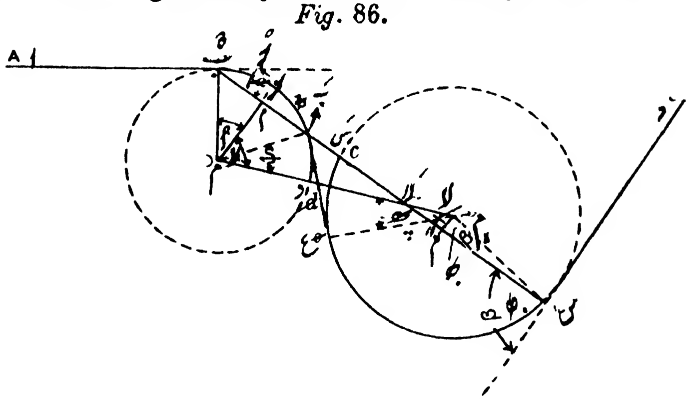
also $BC = r \sin \alpha + 2r \sin \theta + r \sin \beta$.

$\therefore r = \frac{BC}{\sin \alpha + 2 \sin \theta + \sin \beta} = \frac{BC}{\sin 15° + 2 \sin 72° 20 + \sin 20}$

$= \frac{1500}{1 \cdot 2077967} = 1242'$ nearly.

192. Two segments joined by a straight portion.

Fig. 86.



$\left.\begin{array}{l} \text{Given} - \\ BO = r \\ CO' = R \\ FC = l \\ ABC = \pi - \alpha \\ BCD = \pi - \beta \end{array}\right\}$ Required the lengths of the arcs Bb and Ce and also that of be which is a common tangent to the two circles, we have—

$$l = Bo + oo' + Co' = r \sin a + (r \cos a + R \cos \beta) \tan \chi + R \sin \beta$$

$$\therefore \tan \chi = \frac{l - (r \sin a + R \sin \beta)}{(r \cos a + R \cos \beta)}$$

Hence χ is known.

$$\left.\begin{aligned} \text{Now } OO' &= \frac{Oo + O'o'}{\cos \chi} = \frac{r \cos a + R \cos \beta}{\cos \chi} \\ \text{and also } OO' &= \frac{Ob + O'e}{\cos \psi} = \frac{r + R}{\cos \psi} \end{aligned}\right\}$$

$$\therefore \cos \psi = \frac{(R + r) \cos \chi}{r \cos a + R \cos \beta}$$

$$\left.\begin{aligned} \text{Hence } BOb &= (a + \chi) - \psi \\ CO\ e &= (\beta + \chi) - \psi \\ be &= (R + r) \tan \psi \end{aligned}\right\} \text{and required lengths of arcs B } b, \text{ C}e, \text{ and length } be \text{ are known.}$$

Example.—It is required to join two lines of railway with a 1° and 2° curve having a piece of straight. The starting and closing TPs are 8000′ apart and the straight line joining the TPs is observed to make angles of 160° and 140° respectively with the tangents. Given the chainage of the TP of the first curve as 576 + 10, find the chainage of the commencement and end of the piece of straight and the closing TP.

The following data in fig. 85 are known :—

$$\begin{aligned} BO &= 5730 \ (r \text{ for } 1^\circ \text{ curve}). \\ CO' &= 2864{\cdot}9 \ (R \text{ for } 2^\circ \text{ curve}) \\ BC &= 8000 \text{ feet} \\ a &= \pi - 160^\circ = 20^\circ \\ \beta &= \pi - 140^\circ = 40^\circ \end{aligned}$$

$$\text{Now } \tan \chi = \frac{8000 - (r \sin a + R \sin \beta)}{r \cos a + R \sin \beta} = {\cdot}553895$$

$$\therefore \chi = 28^\circ\ 59' \text{ nearly}$$

$$\text{Cos } \psi = \frac{(R + r) \cos \chi}{r \cos a + R \cos \beta} = {\cdot}99198$$

$$\therefore \psi = 7^\circ\ 15\tfrac{1}{2}'$$

$$\therefore \text{ angle BO}b = 41^\circ\ 43\tfrac{1}{2}'$$

$$\text{and angle CO}'e = 61^\circ\ 43\tfrac{1}{2}'$$

and $be = (r + R) \tan \psi = 8595 \tan \psi = 1094{\cdot}7$ feet and therefore the chainage of b the end of the first curve = (576 + 10) + (41 + 72·5) = 617 + 82·5 ; and chainage of e the TP of the second curve = (617 + 82·5) + (10 + 94·7) = 628 + 77·2 and the TP end of the second

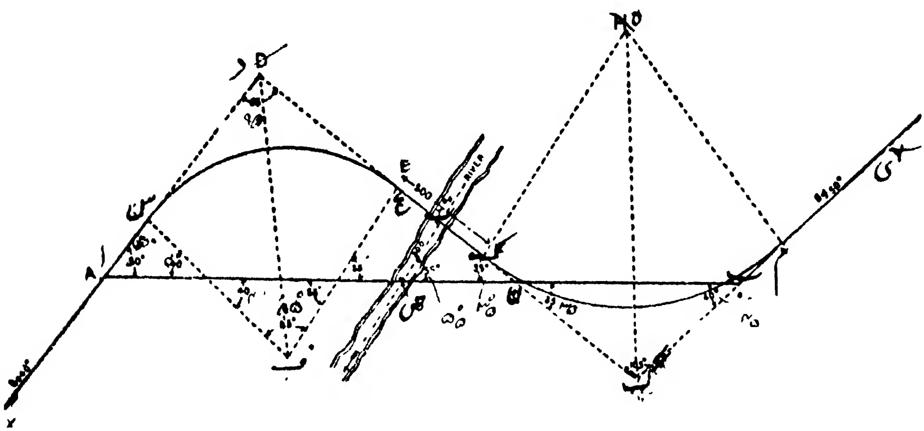
curve = (628 + 77·2) + (30 + 86·3) = 659 + 63·5. The curve would be pegged out by Method 1.

NOTE.—If AB and CD were parallel then angle a would equal the angle β.

193. Problem.—In running a traverse for a line of railway an engineer goes along a line XA bearing 40°. The chainage up to A is 12000. He then turns to the right and continues to a point B 3000 feet from A, the bearing of AB being 90°. From B he changes his direction and continues on at a bearing of 50° to Y. At chainage 13400 he crosses the centre line of a stream 100 feet wide at an angle of 55°. In examining the ground for a site for a bridge he selects a spot 300′ upstream to the centre of the bridge measured along the centre of the stream. The bridge is to be at right angles to the stream.

He now wishes to put in a reverse curve joining up the lines XA and BY and has to leave a piece of straight 250′ on each side of the centre of the bridge. What would be the radii of each of the curves he would use? And where would the reverse curve start and end?

Fig. 87.



In the triangle S T N (fig. 87) we have :—

$$\frac{TN}{300} = \tan 55^\circ$$

$$\therefore TN = 300 \times \tan 55^\circ$$

$$= 300 \times 1{\cdot}428148$$

$$= 428{\cdot}44$$

$$\text{Now } TK = 250 \text{ (by problem)}$$

$$\therefore KN = 178{\cdot}44$$

In the same triangle :—

$$\frac{T\,S}{S\,N} = \cos 55^\circ.$$

$$\therefore S\,N = T\,S \times \sec. 55^\circ = 300 \times 1{\cdot}74344$$
$$= 523{\cdot}03$$

$$\therefore A\,N = 1923{\cdot}03$$

In the triangle ADN

$$\frac{D\,N}{\sin 50^\circ} = \frac{A\,N}{\sin 95^\circ} \therefore D\,N = \frac{A\,N \sin 50^\circ}{\sin 95^\circ}$$

$$\therefore \log D\,N = \log A\,N + L \sin 50^\circ - L \sin 95^\circ$$
$$= 3{\cdot}2839869 + \bar{1}{\cdot}8842540 - \bar{1}{\cdot}9983442$$
$$= 3{\cdot}1698967$$
$$\therefore DN = 1478\;75$$
$$\text{Now } E\,N = 500 + 178{\cdot}44 = 678{\cdot}44$$
$$\therefore D\,E = 1478{\cdot}75 - 678{\cdot}44$$
$$= 800{\cdot}31$$

Again in the triangle DFE

$$\frac{E\,F}{E\,D} = \cot \frac{85^\circ}{2}$$

$$\therefore E\,F = E\,D \cot 42\tfrac{1}{2}^\circ$$
$$\therefore \log E\,F = \log E\,D + L \cot 42\tfrac{1}{2}^\circ - 10$$
$$= \log 800{\cdot}31 + {\cdot}0379475$$
$$= 2{\cdot}9032582 + {\cdot}0379475$$
$$= 2{\cdot}9412057$$
$$\therefore E\,F = 873{\cdot}38$$
$$\text{Now } A\,N = 1923{\cdot}03$$
$$\therefore N\,B = 3000 - 1923{\cdot}03$$
$$= 1076{\cdot}97$$

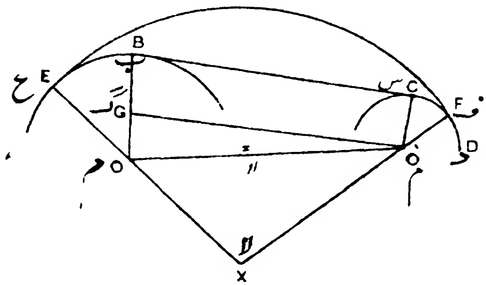
Now in the triangle NGB we know NB and all the angles so we can solve the triangle and therefore know GB and GN we thus know KG, since KG = KN + NG. Knowing KG we find KH ; and in the triangle NBG, GB is found and hence BH is known.

Again in the triangle ADN which we can solve, we find AD. But we know CD. ∴ we know AC.

Then the points C and M the commencement and end of the reverse curve are known and can be measured on the ground. We see that XA will be produced to C for "take off" of the curve and that the reverse curve will end at point M on BY.

194.—To join two curves by a simple curve.—Supposing BC a piece of straight falls across an obstacle it is required to join the two curves by a simple curve and to find the points of tangency. Let AEB be a 3° curve CFD a 4° curve and BC = 600 feet; it is required to lay down a 1° curve to join these two and to find E and F the points of tangency.

Fig. 88.



Let O and O′ be the centres of the two curves. Join BO, OO′ and CO′ and through O′ drawn O′G parallel to CB.

Then in the triangle OGO′; OG = R − R′ = 477·4 and tan GOO′ = $\frac{O'G}{OG} = \frac{600}{477 \cdot 4}$ ∴ GOO′ = 51°·28′ and OO′ = $\frac{O'G}{\sin O'OG}$ ∴ OO′ = 767′

Now since EX the radius of 1° curve = 5729·7′ ∴ OX = 3819·6′ and similarly O′X = 4297·0′

In the triangle OO′X; $\sin \frac{OXO'}{2} = \sqrt{\frac{(S-O)(S-O)}{OO'}}$ where S = half the sum of the sides.

$$\therefore OXO' = 8°{\cdot}30'$$

and $\frac{\sin OXO'}{x} = \frac{\sin O'OX}{O'X}$ ∴ $\sin O'OX = \frac{\sin OX'O \times O'X}{x}$ ∴ XOO′ = 124°·06 and 180° − OXO′ − O′OX = OO′X ∴ angle OO′X = 47°·24′

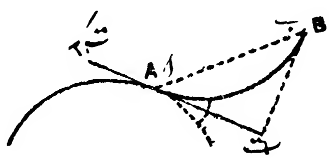
Now angle EOO′ = angle OXO′ + angle OO′X = 55°·54′

and angle EOB = angle EOO′ − angle BOO′ = 4° 26′ and therefore EB or length of curve to tangent point E is known since it is equal to $\frac{EOB \times 100}{3°}$ = 117′·7 and similarly CF = $\frac{CO'F \times 100}{4°} = \frac{4{\cdot}065 \times 100}{4}$ = 101·6′.

The points of tangency are thus found to be 117·7′ back from B as one TP of the new curve and 101·6′ forward from C as the other TP of the new curve.

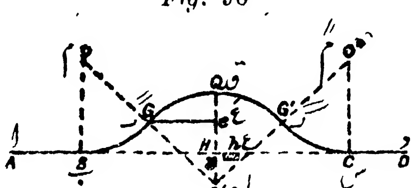
195. Serpentine Curve.—In a serpentine or ogee curve, when an angular instrument is available, the method of setting out the second curve is to set up the theodolite at A, range back on the first tangent point B, set off an angle BAT equal to TBA, add 180°, and lay out the curve from the line AT′ thus obtained. But if no angular instrument is available, the first curve is left, and the second taken up, thus:—When the point A (*the point of contrary flexure*) is reached when setting off the first curve, by setting only half the versed sine the tangent TA is resumed; if then the half versed sine be set off on the other side of the tangent, the first point in the second curve is obtained. The whole the versed sine is used for finding the next point, and so on. Reverse curves should however never be permitted in the main line of a railway, as they involve a sudden change of superelevation from one side to the other. Curves in opposite directions should have at least about 200 feet of straight line between them, and they can then be located, as two independent curves.

Fig. 89.



196. Curve of deviation or diversion—In some cases it may be necessary to make a given deviation from a straight line of railway, so that the works may avoid a building or other obstruction situated on or near it; this is done by means of three curves as follows:—Let ABCD (*Fig.* 90) be a straight portion of the railway, *h* a building or other obstruction on the line. Take HQ of a sufficient length for a deviation, that the line may avoid the object at *h*; and through Q draw a curve GQG′ of radius QO′ equal to, or greater than, one mile. Draw also two curves BG, G′C of like radius, meeting the first curve at G and G′, and the lines at B and C; then the line OO′ and O′O″ joining the centres of the curves, will pass through their points of contrary flexure at G and G′. Put r = common radius OB = O′Q = O C, and d = required deviation = HQ; then BH = HC = $\sqrt{d\,(4r-d)}$, and the four equal chords BG, CG′, etc., are each equal to $\sqrt{dr}$.

Fig. 90



From G draw Ge at right angles to QH. Then G$e = \frac{1}{2}$ BH, and Q$e = \frac{1}{2}$ QH $= \frac{d}{2}$.

In the triangle GO$'e$, $Ge^2 = r^2 - (r - \frac{d}{2})^2$. Hence $Ge^2 = \frac{1}{4}d\ (4r - d)$,

$\therefore\ Ge = \frac{1}{2}\sqrt{d(4r - d)}\ \therefore\ BH = \sqrt{(d4r - d)}$.

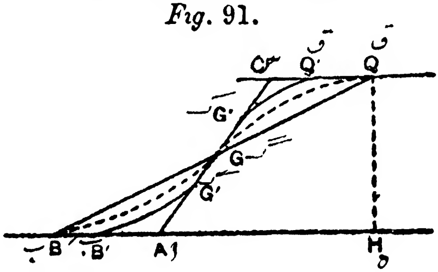
Again $GQ^2 = Ge^2 = Qe^2 = \frac{1}{4}d\ (4r - d) + \frac{d^2}{4} = dr$.

$$\therefore\ GQ = \sqrt{dr}.$$

197. Problem.—During the construction of permanent bridge the line of rails is to be carried over a temporary bridge which is situated 1,200 feet below the permanent bridge. A diversion curve is to be laid out for the line which is to commence on the river side of a railway station the platform of which ends at 3,500′ from the centre of the permanent bridge. Give the necessary calculations for laying out the curve neglecting the length of the bridge.

In figure 91 BH = 3,500′ and QH = 1,200.

Fig. 91.



Now $BH = \sqrt{d\ (4r - d)} = \sqrt{1,200\ (4r - 1,200)}\ \therefore\ r = 2,852{\cdot}08'$.
If we select a curve having r greater than 2852·08 we will get BH greater than 3,500′ which is impossible under the circumstances.

Take the next lower value given in the tables or a radius to a curve of say 2°·6′ curvature or $r = 2728\ 52'$ and by substituting the new radius $\frac{BH}{2}$ will be found equal to 1707·1 $\therefore$ BH = 3414, very nearly.

Now if the angle GBH $= \gamma$ it will represent half the angle of full deviation for each branch of the curve and $\tan \gamma = \frac{1,200}{3\ 414} = {\cdot}351493$ $\therefore\ \gamma$ 19° ·21′ ·9′ or 19° ·22′ very nearly $\therefore\ 2\gamma = \beta = 38°$ ·44′ and length of each branch of the curve $= \frac{38\ 73 \times 100}{2\ 1} = 1844{\cdot}3$ and whole chainage $= 1844\ 3 \times 4 = 7377{\cdot}2$.

Also $BG = \sqrt{ar} = 1809{\cdot}4$ very nearly.

$\therefore\ BQ = 2 \times 1809{\cdot}4 = 3618{\cdot}8'$.

198. Problem.—The foregoing example does not allow for a piece of straight so let us consider the example again with the data already given and set out a suitable diversion with a piece of straight of suitable length between the two curves.

In *Fig.* 91 the dotted line shows the two curves with radius $r = 2852{\cdot}08'$ see previous example with G a point midway between B and Q which is the point of contrary flexure.

From data of previous example $\tan \gamma = \frac{1200}{3500} = {\cdot}3428571 \therefore \gamma = 18^\circ {\cdot}55\frac{1}{2}'$ nearly = angle CQG or CGQ or GBA or BGA.

Now $BQ = \sqrt{QH^2 + BH^2}$ and $BG = \frac{BQ}{2} = 2 R \sin \gamma$ and since γ is known $\therefore$ r is found for the curves starting at B and ending at Q.

Again the tangents BA, AG, GC, CQ are each equal to $R \tan \gamma = 2852{\cdot}08 \times {\cdot}3428571 = 977{\cdot}5'$.

Let the piece of straight required be 70 feet which will be found sufficient for a train travelling on a diversion curve. Then GG′ and GG″ will each equal 35′ or the tangents will be shortened by 35′ and therefore the new tangents will each equal $977{\cdot}5 - 35' = 942{\cdot}5'$ and since γ is constant then by the formula $T = 942{\cdot}5 = R \tan \gamma = R \times {\cdot}3428571$.

$\therefore R = 2183{\cdot}57' \therefore \delta = 2^\circ {\cdot}37'$ very nearly, the curves may be laid down with this angle of curvature or accepting $\delta = 2^\circ {\cdot}37'$ the tangents can be recalculated to get an exact value and B′ G′ G″ and Q′ are measured accordingly. It is to be noted that the points A and C can be marked down on the ground by measuring from B and Q respectively a distance of 977·5′. The direction AC is a check on the work at G′ and G″.

199. General.—In laying down a curve in actual practice, it will be sufficient for all practical purposes to fix points at such intervals that the versed sine of the intercepted arc should not exceed 0·25′, or thereabout. These points may be obtained by off-sets from the tangents when the maximum length of such off-sets does not exceed 30 or 35′, above this limit it will be advisable to adopt the method of off-sets from chords. Calculate the number of chords of a constant length (100′ or 200′ answer best in practice), the length of the remaining chord contained in the curve, and also the angle contained by two successive chords. Proceed to lay them in the usual way with a theodolite and chain, commencing from one end of the tangents; if correctly done, the end of the last chord will fall on the peg marking the termination of the other tangent.

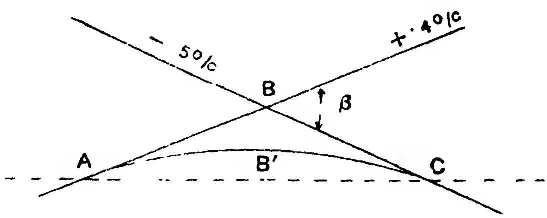
200. Vertical Curves.—In first class railway work Vertical Curves are placed at changes of grade where the algebraic difference of an up grade (plus) and a down grade (minus) exceeds 0·2 feet. In first class American practice it is laid down that the change of grade shall be ·1% per 100 feet at summits and ·05% per 100 feet in sags. It must be remembered that this so called rounding off the grades is to prevent jolts and strains on couplings and is more necessary at low speeds than high.

If a g % up grade meets at g' % down grade then the total change of grade is $+ g - (-g') = (g + g')$ % and the length of the vertical curve will be $\frac{g+g'}{\cdot 1} = 10\,(g + g')$ chains of 100 feet. The total length is always in a full number of chains and therefore if a ·4% or $\frac{1}{250}$ up grade meets a ·5% or $\frac{1}{200}$ down grade the length of the whole curve will be $\frac{+\cdot 5-(-\cdot 4)}{\cdot 1} = 9$ chains or 900 feet for first class railway work in summits and twice that length or 1800 feet in sags.

Theoretically the parabola is the correct curve to lay down but the angle of change is so small that the curve practically becomes a circular curve and can be treated as such as follows:—Example.

After a longitudinal section has been run it was found that a ·4% gradient is to be laid down to meet a ·5% gradient on a summit.

Fig. 92.



·4% gradient = $\frac{1}{250}$ = ·004 = nat. sine of 14′
·5% gradient = $\frac{1}{200}$ = ·005 = nat. sine of 17′
Therefore total deflection angle = 31′ = β

Since the whole curve is 900 feet, each tangent may be taken as 450′ each way from the apex or highest point.

$$\text{Since } T = R \tan \frac{\beta}{2}$$

$$\therefore 450 = R \tan \frac{31'}{2}$$

$$\therefore R = \frac{450}{\cdot 0045} = 100{,}000$$

The tangential offset for the first peg from the TP or A $= \frac{100 \times 100}{2 \times 100{,}000} = \frac{1}{20} = \cdot 05$

The second offset at 200′ will be $2^2 \times 05 =$ ·20 feet.
third „ „ 300′ „ „ $3^2 \times \cdot 05 =$ ·45 feet.
fourth „ „ 400′ „ „ $4^2 \times \cdot 05 =$ ·80 feet.
apex „ „ 450′ „ „ $(4\ 5)^2 \times \cdot 05 =$ 1·01 feet, etc , etc.

(Compare formula apex distance $= \mathrm{T} \tan \frac{\beta}{4} = \mathrm{BB'}$

$$= 450 \tan \frac{31'}{4}$$

$$= 450 \times \cdot 002254 = 1{\cdot}01 \text{ feet.}$$

Let the reduced level of the T.P. or B.C. at A be 100·00, with an up grade of ·4°/₀ the reduced level of the intersection point at B = 100′ + (·4 × 4·5) = 101·80′ and with a down grade of ·5°/₀ the reduced level of the end of the curve at C = 101·80 – (·5 × 4·5) = 99·55′. It is necessary therefore to put into tabular form the reduced levels at 100′, 200′, etc., along the tangents or grade and subtract* from these the offsets respectively to obtain reduced values on the curve for formation level as follows :—

Sta.	Tangent R L.	Offset.	R.L. on curve.
B. C. (T.P.)	... 100·00	—	100·00
100	... 100·40	·05	100·35
200	... 100·80	·20	100·60
300	... 101·20	·45	100·75
400	... 101·60	·80	100·80
Apex 450	... 101·80	1·01	100·79
500	... 101·55	·80	100·75
600	... 101·05	·45	100·60
700	... 100·55	·20	100·35
800	... 100·05	·05	100 00
900 (E.C.)	... 99·55	—	99 55

The whole of this curve could not be laid down from one station point, perhaps two or more "sets up" would be needed or it might conveniently be laid down from opposite directions with the apex peg as a check. What is necessary in these cases is to add the height of the instrument at the peg, obtain a new Height of Instrument or Collimation line and then the reduced levels by subtraction according to above table. It would be considered good practice to have a vertical curve on a summit on an embankment as it would require less earth for filling and

* The offsets are minus on summits and plus on sags.

vice versa, a sag in cutting as it would require less excavation. There are also two other cases of two up grades or two down grades meeting with different gradients and the same formula applies.

201. Transition Curves.—On a curve the outer rail must be higher than the inner rail on account of the overturning moment known as "centrifugal force". The amount of superelevation necessary will be due to the degree of curvature and the speed of the train. There are two forces acting :—

(1). The weight acting downwards.

(2). The centrifugal force acting outwards.

The superelevation must not be so great so that when the train stops on the curve the line of action of W falls without the rails and it must be sufficient for the speed so that the resultant of the two forces acts between the rails and perpendicular to it.

Ordinary Indian practice was to widen the gauge on the curve and to give all the superelevation necessary on the straight on the outer rail before the train entered the curve. This is not conducive to comfort and produced shocks and any thing but smooth running. The transition curve has been substituted so that the process of entry from the straight or tangent to the circular arc or curve shall be gradual, hence its name. The superelevation is gradually given to the outer rail of the transition curve usually known as the length of adjustment (l).

Froude * lays down if superelevation is applied at 1 in 300 then $l = 300 \times$ superelevation. Superelevation = gauge in feet $\times \frac{v^2}{1{\cdot}25\ R}$ and for the standard gauge in India, that of 5′·6″, and a speed v of 60 miles † per hour, we obtain 8·08″ as superelevation for a 3° curve and thus $l = 300 \times 8{\cdot}08' = 202'$.

Mr. Morrison in his practical method accepts 200′ as l or the length of the curve of adjustment. It is necessary now to find the *Shift* as it is called or the amount the circular arc is shifted towards its centre so that the length of adjustment curve shall, so to speak, merge readily into the new arc.

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* See Proceedings Institution Civil Engineers, Volume CLXXVI

† Superelevation rarely exceeds 5½″ in India the maximum speed of trains being more or less confined to 45 miles an hour. Again if 1″ is given to each 36′ rail and 5½″ a maximum 36 × 5½″ gives l the length of the curve as 198′ or 200′ for the purposes of laying down the transition.

(For practical purposes and except for very sharp curves it is unnecessary to obtain a new radius for this arc which theoretically is R-shift).

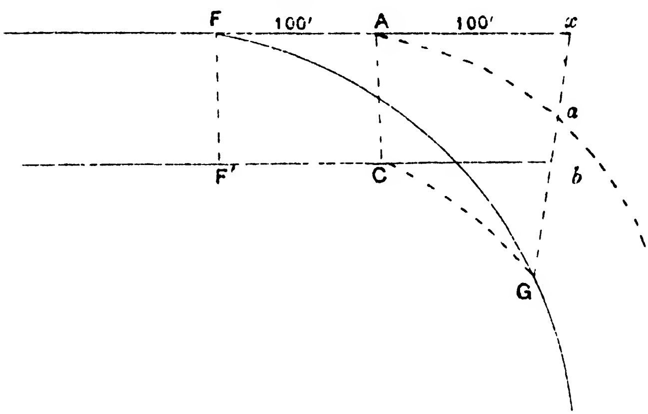
Shift or s is best remembered as being equal to $\frac{l^2}{24\ R}$ in feet or $\frac{l^2}{2R}$ in inches as the latter is analogous to the tangential offset formula $\frac{C^2}{2R}$.

Taking $l = 200'$ and $\delta = 3°$ then shift in inches * $= \frac{(200)^2}{2 \times 1910} = 10{\cdot}47''$.

In figure 93 the original curve started from A. It is required to put in a transition curve.

From A lay off a point C = 10·47″ towards the centre of the curve

Fig. 93.



or at right angles to tangent will be accurate enough. AC represents the shift. From A measure AF back along the tangent 100′ and also Ax towards the intersection point 100′. From x lay an offset equal to tangential offset xa plus shift $s = xa + s = \frac{C^2}{2R} + 10{\cdot}47'' = 2{\cdot}62' + {\cdot}87' =$ $3{\cdot}49'$. Call this peg G and G is the beginning of the new circular arc. Join FG and it will be found that FG will bisect AC. Also FG will conform very closely to a cubic parabola such that all offsets from the original tangent to FG will be in proportion to the cubes of the distances from F or

$$(Fx)^3 : (FA)^3 :: 3{\cdot}49 \cdot p$$

$\therefore\ p = \frac{100 \times 100 \times 100 \times 3{\cdot}49}{200 \times 200 \times 200} = {\cdot}435'$ where $p = \frac{1}{2}$ AC $= \frac{1}{2}$ shift $= \frac{10\ 47}{2} =$ $\frac{{\cdot}87'}{2} = {\cdot}435'$.

* Shift is also given for a 200′ length as equal in feet to $\frac{16{\cdot}6}{\text{Radius of curve in chains of 100 feet}}$ $= \frac{16{\cdot}6}{19{\cdot}1} = 10\ 44$ inches.

After doing the preliminary work at A set up the theodolite at C align back on the new tangent CF′ and complete the circular arc from G onwards.

Transition curves between two reverse curves should change curvature at the same rate in order that at the junction point no sudden change in superelevation is felt. In the event of two reverse curves, where a piece of straight to join them is impossible, both curves would be shifted towards their respective centres by the calculated amount of shift and the transition curve would then pass through what would have been the point of contrary flexure.

202 Government of India rules.—The following paragraphs are copied from "Rules for the preparation of Railway Projects, 1918."

"100. The most suitable curve, for the transition from a straight line to a circular curve, is a spiral curve known as the 'cubic parabola': the formula connecting the length of the transition spiral with the inward 'offset or 'shift' of the crown of the circular curve is $S = \frac{l^2}{24r}$, where S = the 'shift' in feet, l = the length of transition curve in feet and r = the radius of the original or primary' circular curve in feet.

101. The proper length of a transition spiral depends on the maximum permissible speed on the circular curve which is being approached: it follows that a longer transition is required for an easy curve than for a sharper one, because the permissible speed is greater.

102. From principles laid down in pages 97 104 of Vol CL XXVI of the proceedings of the Institution of Civil Engineers, in a paper by Mr. W. H Shortt we can deduce that (with certain limitations) the minimum length (in feet) for a transition spiral should be about $8\sqrt{r}$ or $606 \div \sqrt{D}$, where r = 'radius of curve in feet' and D = 'degree of curve.'

103. With this length of transition spiral the 'shift' is exactly 2 feet 8 inches for all circular curves which have to be joined to a straight line.

104. The formula $8\sqrt{r}$ or $606 \div \sqrt{D}$, gives too great a length of transition spiral for curves flatter than 2° (radius = 2,865 feet). For such curves a suitable length (in feet) for the transition spiral is given by the formula.

6 × (maximum permissible speed in miles per hour).

105. The formula may also be used in cases where it is undesirable to provide so long a length of transition spiral as would be required by the formula $8\sqrt{r}$, —

FOOT-NOTE :—*For* more exact methods *see* paper No 3065 Vol. CXXXIII Proceedings Civil Engineers by J. Robinson, M.I.C E, and the College Railway Manual, Searle's Spirals, etc.

for instance between reverse curves on a mountain railway in places where speed may be restricted to something less than $1\frac{1}{3}\sqrt{r}$. If the length of transition spiral is less than $8\sqrt{r}$, the shift of the circular curve will, of course, be less than 2 feet 8 inches."

203. Alignments and Setting out.—Alignments whether for a canal, distributary of a canal, a railway or road would be ordinarily first reconnoitred and set down on a standard one inch map of India. The reconnaissance alignment may consist of one or more proposals and for choice the map could be mounted on an ordinary planetable the sight rule being used for resection and possibly the tangent clinometre in the case of railways and roads would be deemed accurate enough for laying down gradients though for canals and distributaries a level would almost be compulsory and preferably one with a compass.

The alignment will consist of straights and curves and a previous chapter has treated on the curve and there remains one caution to be added concerning the lay out of the straight.

204. The double centre method.—As instruments invariably have errors in graduation and otherwise it is not accurate enough to suppose that a telescope or sight vane swung through 180° will be a means of producing a straight line. As the theodolite would generally be used for the purpose of a railway there are not only graduation errors. both of plate and verniers and the setting of the same, to be considered but transit axis errors and the method to be employed is as follows.—Centre up and level the theodolite very carefully over the last peg and clamp the upper plate. Unclamp the lower plate and set telescope on the back flag clamp and use slow motion screw to intersect. Next transit telescope without unclamping either plate or touching footscrews and resect the forward flag, putting down a peg. Unclamp lower plate and swing the telescope on to the back flag, clamp and intersect as before and again transit telescope and intersect forward flag. If the flag is found to be over the peg put down previously the alignment is a straight line and correct; if not put down a second peg and the true straight line will pass through the mid-point between the two pegs. It should be noted that the observation has been made on both faces and that no readings have been taken.

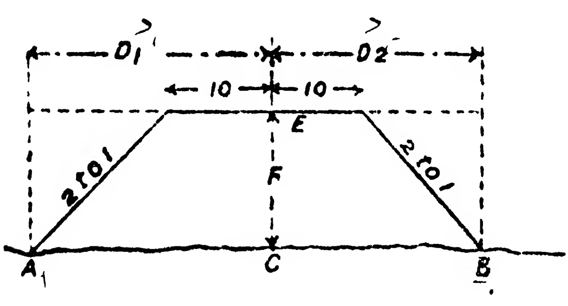
Besides the straights and curves which constitute the plan of the alignment the engineer is concerned with the gradient and this book can treat only of the methods of survey rather than the grades which should be laid down. The profile along the aligument is known as the *Longitudi*

nal section and the preliminary location is usually laid down irrespective of the curves that is the intersection points of tangents are marked, gradients then calculated and curves projected and examined to meet the requirements of the grades in question since maximum gradients must be confined to the straights.

The positions of crossings of roads and streams, wells and station sites will be considered and also the cost of earthwork in excavation and embankments. For the latter purpose level values at right angles to the longitudinal section are taken from which an estimate is prepared. These are known as *Cross sections.*

205 Grade Staff method.—Here follows what is known in location work as setting slope stakes that is when the engineer has satisfied himself as to his alignment and grades, stakes are set as a guide for the contractor in the matter of filling or cutting. In calculations the minus sign denotes a fill as it is the quantity of material short and likewise a cut as plus as it is quantity in excess. The Canadian practice is known as the *Grade Staff Method* and it is here explained.

Fig. 94.



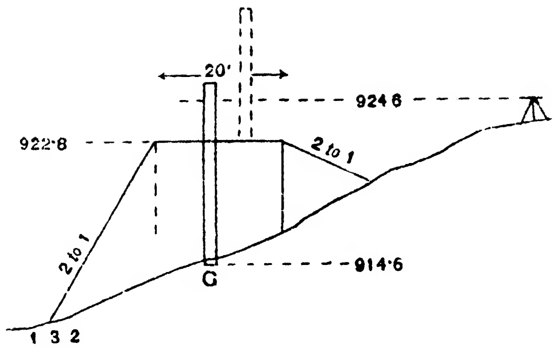
206 Fill.—In fig. 94 the formation level of an embankment is 20 feet wide the side slopes are 2 to 1 and ACB is a moderately level piece of ground C being a peg on the longitudinal section with a reduced level value. If CE or F is 8 feet then D_1 and D_2 the "distances out" $= 10 + 2\,F = 26$ feet.

In entering values in the cross section book this would read as follows :—

L	C	R
$\dfrac{-8{\cdot}0}{26}$	$-8{\cdot}0$	$\dfrac{-8\ 0}{26}$

The minus quantities denoting a fill or quantity short, the numerators the amount of fill and the denominators the distance out.

Fig. 95.



Take the next example of fill on sloping ground and in figure a rod is shown in firm lines and one in dotted lines, which latter is supposed to be the rod on top of the completed embankment and is known as the Grade Staff Rod and the Grade Staff *Height* is the difference between the height of eye at the instrument and the R. L. of the formation level. In this case 924·6 —922·8′ = 1·8′.

Let us consider the case of the Engineer arriving at the peg at C and on consulting his level book he finds that it is peg No. 110 + 40 He is required to put down slope stakes as a guide to the contractor. He sets up his level at right angles to the aligument and finds on reading to a staff on the peg C that he obtains a value for the height of the instrument collimation line (H.I.) as 924·6 From his grade record he finds that the formation level at C is 922·8 so he obtains 1·8 as his grade staff height and 922·8—914·6 = - 8·2 as Fill at C. The staff man is moved to a point which is thought to be the further toe of the slope. A reading is taking on the staff as 10·8.

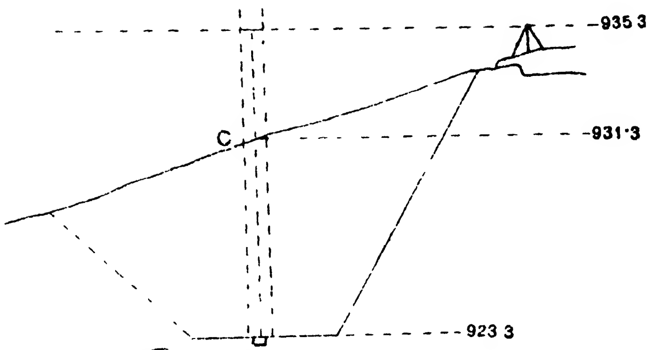
∴ Fill 10·8—1·8 (grade staff height) = 9 feet and distance out from C will be 9 + 9′ (2 to 1 slope) + ½ width = 2 × 9′ + 10′ = 28 feet but the measure is actually 25 feet and another trial is made.

At point 3 the staff reads 9′ ∴ fill = 9′—1·8′ = 7·2′ and distance out is 2 × 7·2 + 10 = ~~24·2~~ 24.4 and the actual measure from the peg C is 24 feet 3 inches so this point was accepted. For the nearer toe let the staff read 5·4′ so fill = 3·6 and distance out from C = 3·6 2 + 10·0 = 17·2 and the measure was found to be 17 feet so this was accepted and thus the entries are as follows :—

$$\frac{-7\cdot 2}{\cancel{24\cdot 2}\ 24.4} \qquad -8\cdot 2 \qquad \frac{-3\cdot 6}{17\cdot 2}$$

207. Cutting.—The next example will be one of excavation or quantity in excess.

Fig. 96.



As before the Engineer obtains the values for formation level as 923·3. R. L. of peg C at station 114 + 40 as 931·3 and H.I. as 935·3. The grade staff height is 935·3 − 923·3 = 12 feet and therefore ~~fill~~ Cutting at centre = 931·3 − 923·3 = 8 feet For the further slope peg let the staff read 5·85 therefore the grade staff height = 12 − 5·85 = 6·15 and the distance out from C = 6·15 × 2 + 10 = 22·3 feet ; for the nearer edge of slope let the staff read 1·85

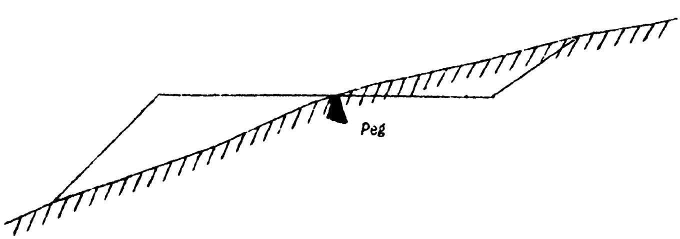
∴ Distance out = 10·15 × 2 + 10 = 30·3 and we obtain values as follows:—

$$\frac{+6{\cdot}15}{\cancel{23{\cdot}3}}\ 22{\cdot}3 \qquad +8 \qquad \frac{+10{\cdot}15}{30{\cdot}3}$$

If the formation changes from cut to fill or *vice versa* grade pegs are put down where the change takes place this also applies to a grade peg coinciding with the ground surface on a side slope.

Take such a case of a grade peg coinciding with the ground level as at station 111 + 40 where R. L. of 923 3 will be also equal to the grade

Fig. 97.



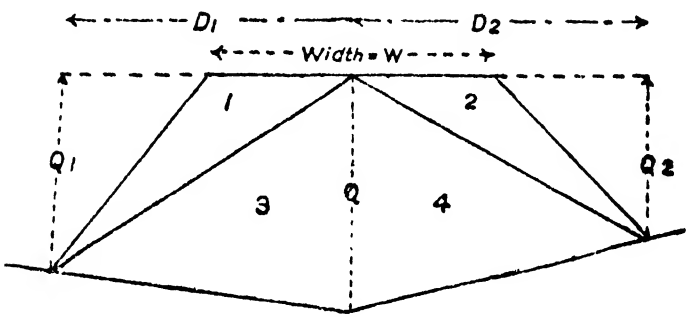
staff heignt 923·3 and continuing as before we obtain say

$$\frac{-4{\cdot}0}{18} \qquad 0{\cdot}0 \text{ and } \qquad \frac{+1{\cdot}3}{12{\cdot}4}$$

and therefore a section of ground as sketched in Fig. 97.

208. Areas.—We must consider next the calculation of areas and

Fig. 98



if we take the fig. as an example we obtain areas 1, 2, 3 and 4 which make up the trapezoid. D_1 and D_2 are distances out and Q are quantities of Fill or Cut as the case may be and W = width of formation.

$$\left.\begin{aligned} \text{Area of } 1 &= \frac{W}{2} \times \frac{Q_1}{2} \\ 2 &= \frac{W\,Q_2}{4} \\ 3 &= \frac{D_1 \times Q}{2} \\ 4 &= \frac{D_2 \times Q}{2} \end{aligned}\right\} \therefore \text{Area} = \frac{W}{4}(Q_1 + Q_2) + \frac{Q}{2}(D_1 + D_2)$$

or area is equal to *sum of side fills or cuts multiplied by ¼ width of formation plus half centre fill multiplied by sum of distances out*, and the area of the previous example of quantity short or

$$\frac{-7{\cdot}2}{24{\cdot}2}\ 24.4 \qquad -8{\cdot}2 \qquad \frac{-3{\cdot}6}{17{\cdot}2}$$

will give a result as follows :-

$$\begin{aligned} \text{Area} &= (7{\cdot}2 + 3{\cdot}6)\,\frac{20}{4} + \frac{8{\cdot}2}{2}\,(24{\cdot}4 + 17{\cdot}2) \\ &= 54 + 168{\cdot}5 \\ &= 224{\cdot}56 \text{ square feet} \end{aligned}$$

and similarly

$$\frac{+6{\cdot}15}{23{\cdot}3} \qquad +8 \qquad \frac{10{\cdot}15}{30{\cdot}3}$$

$$\begin{aligned} \text{Area} &= (6{\cdot}15 + 10{\cdot}15)\,\frac{20}{4} + \frac{8}{2}\,(23{\cdot}3 + 30{\cdot}3) \\ &= 87{\cdot}5 + 214{\cdot}4 \\ &= 295{\cdot}9 \text{ square feet.} \end{aligned}$$

and vol. per 100′ = 295·9 × 100 = 29590 cubic feet.

$$= \frac{29590}{27} \text{ cubic yards.}$$

The area for cross section at 111 + 40 would work out as follows :—

$4{\cdot}0 + 1{\cdot}2 \times 5 + 0 \times 30{\cdot}4 = 26$ square feet that is total cut and fill and to separate the quantities we obtain.

$4{\cdot}0 \times 5 = 20$ as embankment and $1{\cdot}2 \times 5 = 6$ as excavation.

209. Volumes.—Further in the case of Volumes.

(1). Where there are two ends, volume $V = \frac{\text{Sum of areas}}{2} \times$ Distance.

(2). Where one end tapers away to a line, $V =$ area of end $\times \frac{D}{2}$

(3). Where one end tapers to a point $V =$ area of end $\times \frac{D}{2}$

The following few points will be found to be useful as hints.

Squared paper or section paper is used for profiles if not in the finished location plan and section at least for the reconnaissance work. Scales generally are Longitudinal Section 1″ = 200′ or 400′ vertical scales 1″ = 20′. Such a profile is painted in as work progresses or a tracing of it is kept up to date each week or month being coloured differently. Attempts should always be made to equalise cutting and filling. If excavation is more than the embanking it will mean spoil or waste of material wh˙ h is surplus and is a sign of indifferent engineering ; on the other hand the opposite case is one of borrow pits which become breeding grounds for mosquitoes. The question of free haul, direction of haul, overhaul must be carefully considered and here again diagrams are usually made in different colours denoting the disposal of quantities fill or cut. Borrow pits should be outlined by the engineer and should be excavated where it is possible the rain water will drain away. Shrinkage of embankment at so much per cent. is to be allowed for and the formation width of a cutting will naturally be wider than an embankment to allow for side drains to take away storm water.

It is necessary now to give a specimen copy of a cross section form showing slope stake set out and the computation of areas.

FORM FOR COMPUTATION OF CROSS SECTIONAL AREAS.

Station or Peg No.	Back Sight.	H. I.	Staff.			R. L.	Grade.	Grade Staff Height.	Embankment −			Excavation. +			Area	
			L	C	R				L	C	R	L	C	R	−	+
110 + 40	10 0	924·6	9·0	10·0	5·4	914·6	922·8	1·8	$\frac{7·2}{24·2}$	8 2	$\frac{3·6}{17·2}$				222·5	
111 + 40	2·0	925·3	6 0	2·0	0·8	923· 3	923·3	2·0	$\frac{-4 0}{18}$	0·0			0·0	$\frac{+1 2}{12·4}$	20·0	6·0
112 + 40	1·5	928·3	4·5	4·5	4·5	923.8 ~~920·8~~	923·8	4·5	0·0	0·0	0·0				0	0
113 + 40				level											0	0
114 + 40	4·0	935·3	4·6	4 0	0·6	931·3	923·3	12·0				$\frac{6·15}{23·3}$	8	$\frac{10·15}{30·3}$		291·9
								etc. etc.								

CHAPTER VIII.

USEFUL PROBLEMS IN SURVEYING.

210. To draw upon the ground a straight line through two given points.—Plant a picket, or staff, at each of the given points, then fix another between them, in such a manner that when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.

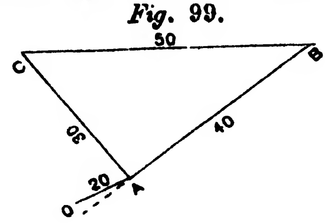
211. To walk in a straight line from a point to a given object.—Fix upon some point, as a bush, or a stone, or any mark that you may find to be in a line with your given object, and walk forward, keeping the two objects strictly in line, and always selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe—that to walk in a direct line, it is always necessary to have *two* objects constantly in view.

212. To trace a line in the direction of two distant points.—Let two persons separate to about 50 or 60 paces; then by alternately motioning each other to move right or left, they soon get exactly into line with the distant objects; or for greater accuracy, they may hold up staves.

In sketching ground, it is constantly necessary to get in line between two objects: if these are not very distant, any one can always do so within a few paces by fronting one object exactly, and then facing to the right about; when if he finds himself accurately fronting the other object, he will be tolerably well in line with them. A right angle may also be formed very nearly, by fronting an object, and then facing to the *right* or *left*.

213. To lay off a perpendicular with the Chain.—Suppose A the point at which it is required to erect a right angle; fix an arrow into the ground at A, through the ring of the chain, marking twenty links; measure *forty* links on the line AB, and pin down the *end of the chain* firmly at that spot B, then with a tape or another chain erect on

Fig. 99.

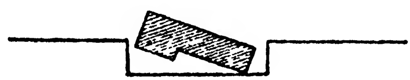


AB a triangle with the other sides equal to 50 and 30 links respectively as shown in the figure the sides of the triangle are then in the proportion of three, four and five, and consequently CAB must be a right angle.

An angle equal to any other angle can also be marked on the ground, with the chain only, by measuring equal distances on the side containing it, and then taking the length of the chord : the same distances, or aliquot parts thereof, will of course measure the same angle.

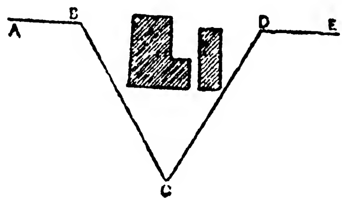
214. To avoid an obstacle, such as a house, in your chain line.—The usual way of avoiding an obstacle of only a chain or two in length, such as a house is by turning off to the right or left at right angles till it is passed, and then returning in the same manner to the original lines.

Fig. 100.



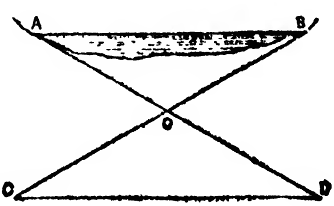
A more convenient method is to measure, on a line making an angle of 60° with the original direction, a distance sufficient to clear the obstacle and to return to the line at the same angle, making CD = BC ; the distance BD is then equal to either of these measured lines.

Fig. 101.



215. To find the length of the line AB accessible only at both ends.—Having fixed on some convenient point O, measure BO and AO ; and prolong those lines till OC = OB, and OD = OA ; then the distance between the points D and C will be equal to AB, for the sides of the triangles COD, BOA, about the equal angles at O, are respectively equal ; therefore the third sides CD, BA will also be equal.

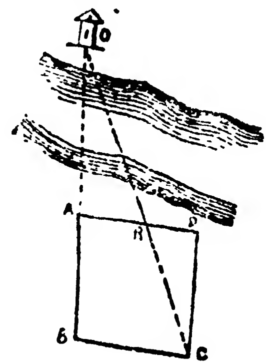
Fig. 102.



216. To find the distance of an inaccessible object O by means of a rhombus.—With a line or measuring tape, whose length is equal to the side of the intended rhombus, lay down one side BA in the direction BO; and let BC, another side, be in any convenient direction; fasten two ends of two of those lines at C and A; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines AD, CD, will form the other two sides of the rhombus. Set up a mark at R, where OC, AD, intersect; and measure RD; then the sides of the triangles RDC, CBO, being respectively parallel, the triangles will be similar hence.

RD : DC :: CB : BO.

Fig. 103.

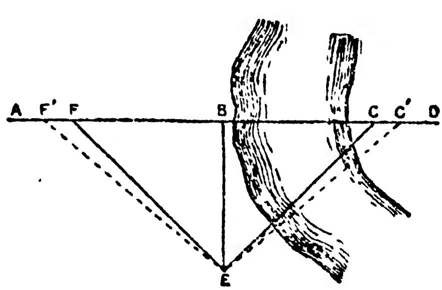


Suppose the side of the rhombus is 100 feet, and RD = 11 feet, 7 inches—then, $11\frac{7}{12}$: 100 : : 100 : 863 *feet nearly* = BO.

If the ground be nearly level, a rhombus, whose side is 100 feet, will determine distances to the extent of 300 yards within a very few feet of the truth. The principle involved in the above is best understood by imagining a tape of 100 feet stretched around ABCD so that the figures for 0, 25, 50, 75, and 100 feet touch pegs at ABCDA; any multiple of the above may be taken to suit the case.

217. To find the length of the line AD, inaccessible at the point D—The measurement of the line AD, supposed to be run for the determination of a boundary, is stopped at B by a river or other obstacle.

Fig. 104.

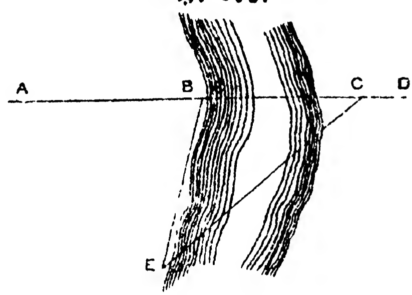


The point F is taken up in the line at about the estimated breadth of the obstacle from B; and a mark set up at E at right angles to AD from the point B, and about the same distance as BF. The theodolite being adjusted at E, the angle BEC is made equal to BEF, and a mark put up at C in the line AD; BC is then evidently equal to the measured distance FB,

If the required termination of the line should be at any point C′, its distance from B can be determined by merely reversing the order of the operation, and making the angle BFE′ equal to BEC′, the distance BF′ being subsequently measured. There is no occasion in either case to *read* the angles. The instrument being levelled and clamped at zero, or any other marked division of the limb, is set on B: the *upper plate* is then unclamped and the telescope pointed at I, when being again clamped, it is a second time made to bisect B; releasing the plate, the telescope is moved towards D till the vernier indicates zero, or to whatever number of degrees it was first adjusted, and the mark at C has then only to be placed in the line AD, and bisected by the intersection of the cross wires of the telescope.

If it is impossible to measure a right angle at B from some local obstruction, lay off any convenient angle ABE and set up the theodolite at E. Make the angle BEC equal to *one-half* of ABE, and a mark being set up at C in the prolongation of AB, BC is evidently equal to BE, which must be measured, and which may at the same time be made subservient to the purpose of delineating the boundary of the river.

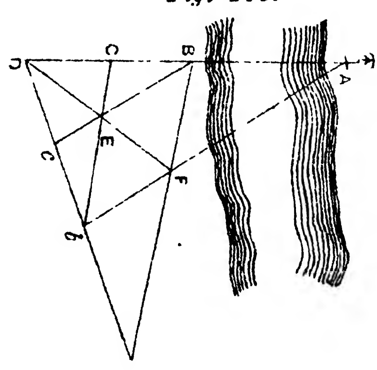
Fig. 105.



The reasoning of this is very simple; the angle ABE = the two angles BEC and BCE; but BEC is half ABE, consequently BCE is half ABE; therefore BEC = BCE, and therefore BC = BE.

218. To find the distance to any inaccessible point on the other side of a river, without the use of any instrument to measure angles.—Prolong AB to any point D; making BC equal to CD; lay off the same distances in any direction D*c*–*cb*: mark the intersection E of the lines joining B*c*: and C*b* mark also F the intersection of DE produced and of A*b*–produce D*b* and BF, till they meet in *a*, and

Fig. 106.

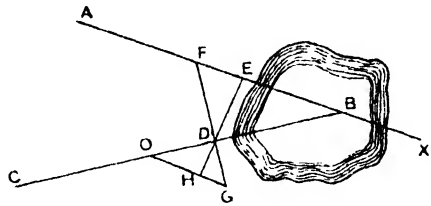


$$\left.\begin{aligned} ab &= AB \\ ac &= AC \\ aD &= AD \end{aligned}\right\}$$

From the similarity of the figure the reasoning is self-evident.

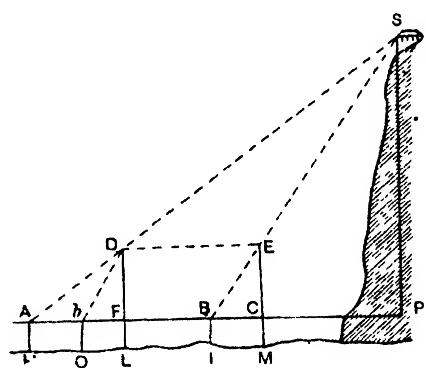
219. To find the point of intersection of two lines meeting in a lake or river and the distance DB to the point of meeting.—From any point F on the line AX draw FD, and from any other point E draw ED, produce both these to H and G, making the prolongations either equal to the lines themselves, or any aliquot part of either length, suppose one-half; join GH, and produce it to O, where it meets the line CB, then OH is one-half of EB, and OD equal to half of DB; which results give the point of intersection B, and the distance to it from D.

Fig. 107.



220. To find the height of a point on an inaccessible hill without the use of instruments.—Drive a picket three or four feet long at H, and another at L, where the top of a long rod FD is in a line with the object S from the point A (the heads of these pickets being on the same level); mark also the point C where the head of the rod is in the same line with S, from the top of any other picket B, and measure AF and BC; lay off the distance BC from F to b, and the two triangles ADb and ASB, are evidently similar, whence,

Fig 108.



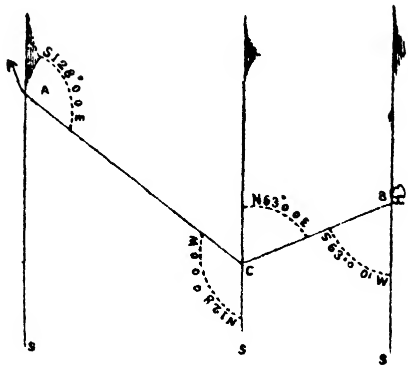
$$\frac{PS}{DF} = \frac{AS}{AD} = \frac{AB}{Ab} = \frac{HI}{HO} \text{ and } \frac{AP}{AF} = \frac{AS}{AD} = \frac{AS}{Ab} = \frac{HI}{HO}$$

therefore $PS = \frac{DF\,HI}{HO}$ and $AP = \frac{AF \cdot HI}{HO}$.

221. To find your place in a Survey—Let A and B be two stations, whose places are fixed, and c, the point to be determined. A very little thought will convince the student that the two bearings of any line as read at both ends must bear some fixed relation to each other; such relation being a constant difference of two right angles. Take the bearing of A, 128° N.-W.; consequently C bears from A, 128° S. E.

Adjust the protractor at A, by means of the east and west parallel

Fig. 109.



lines, and lay off 128° S. E. the bearing of C; which point C must lie somewhere in the line thus obtained. Next, take the bearing of B63° N. E. and having adjusted the protractor at B, lay off 63° S. W., and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

The above may be put into a short rule, thus—*To find a station by observations taken to two points already known.* Protract *from* those points the *opposite* bearings to those observed; their intersection fixes the place sought. For example, if the bearing to a point be 20°, protract from that point 200° (= 180 + 20), etc.

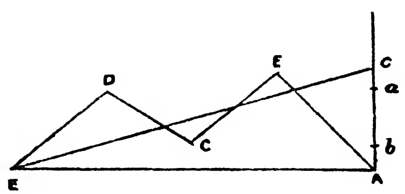
Note.—That the nearer the two bearings meet at a right angle, the more correct will the station be determined; and also, that when a third fixed point can be seen, a bearing to it will serve to corroborate the other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as well defined as any other point.

The above is a very useful problem; and indispensable when sketching ground and filling in a survey.

222. To reduce the off-set piece ABCDE to a right-angled triangle AEc of the same area, by an equalizing line Ec, with the parallel ruler.

Draw the indefinite line A*c* perpendicular to AE. Lay the parallel ruler from A to C: hold the near side of the ruler firmly, and move the further side to B, which will cut A*c* at *a*, where a mark must be made. Lay the ruler from *a* to D, and the further side thereof being now held

Fig. 110.



fast, bring the near side to C, making A*c* at *b*. Lay the ruler from *b* to E, move it parallel to D, marking A*c* at *c*. Join E*c*; then AE*c* is the right-angled triangle required, and its area may be found by taking half the product of AE and A*c*.

The reasoning for the above various steps will be at once seen on reference to page 39, where the method of reducing a polygon to a triangle is described.

223. General Rule for solving Problems of this kind.—Draw a temporary line, as A*c*, at right angles, or at any other angle to the chain line, as AE, of the off-sets.

1. Lay the ruler from the first to the third angle, and move it parallel to the second angle; then make the first mark on the temporary line.

2. Lay the ruler from the first mark on the temporary line to the fourth angle, and move it parallel to the third angle; then make the second mark on the temporary line.

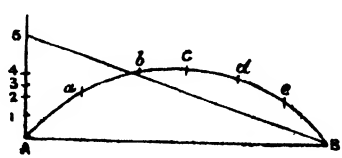
3. Lay the ruler from the last-named mark to the fifth angle, and move it parallel to the fourth angle, then make the third mark on the temporary line.

4. Lay the ruler from the last-named third mark on the temporary line to the sixth angle, and move it parallel to the fifth angle; then make the fourth mark on the temporary line.

In this manner the work of casting by the parallel ruler may be conducted to any number of angles. Great care must be taken during the operation to prevent the ruler slipping, as such an accident will derange the whole of the work, if not discovered and immediately corrected.

224. To reduce a curved off-set piece to a right-angled triangle of the same area.—Let A*abcde*B be the curved off-set piece. Divide the curve by points *a*, *b*, etc., so that the parts A*a*, *ab*, etc., may be nearly straight; and draw A5 perpendicular to AB. Lay the ruler from A to *b*; move it parallel to *a*, and mark A5 at 1. Lay the ruler from 1 to *c*; move it parallel to *b*, and mark A5 at 2. Lay the ruler

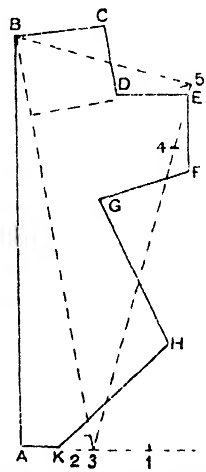
Fig. 111.



from 2 to d; move it parallel to c and mark A5 at 3. Lay the ruler from 3 to e; move it parallel to d, and mark A5 at 4. Lay the ruler from 4 to B; move it parallel to e, and mark A5 at 5. Draw the line B5: then will AB5 be a right-angled triangle equal in area to the off-set piece A*abcde*B, as required.

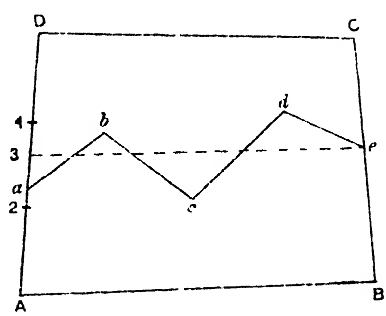
225. To reduce the irregular field ABCDEFGHK to a trapezium of the same area.—Prolong the line AK at pleasure. Lay the ruler from K to G: draw a parallel line through H, and mark AK prolonged at 1. Lay the ruler from 1 to F; move it parallel through G, and mark AK at 2. Lay the ruler from 2 to E: move it parallel through F, and mark A 1 at 3. Draw a line 3 to E and prolong from E. Lay the ruler from E to C; move it parallel through D, and mark 3 E at 4. Lay the ruler from 4 to B: move it parallel through C and mark 1 E prolonged at 5. Draw a line from 5 to B; then shall AB53 be a trapezium, equal in area to the irregular figure ABCDEFGHK; the area of which may be found by multiplying the diagonal B3 by half the sum of the perpendiculars thereon from A and 5.*

Fig. 112.



226. To draw an equalizing line through the crooked fence, abcde, so that the two fields ABea, aDCe, may be four-sided.—Lay the ruler from a to c: move it parallel to b, and mark AD at 1. Lay the ruler from 1 to d: move it parallel to c, and mark AD at 2. Lay the ruler from 2 to e; move it parallel to d: and mark AD at 3. Draw the line e3, and it will divide the two fields so that their quantities shall be the same as those before separated by the crooked fence *abcde*.

Fig. 113.



* NOTE.—In this manner the crooked sides of a field may be successively reduced to straight ones. Thus if the side AB had been crooked, the operation of straightening might be continued by prolonging the dotted line 5B, and find successive points therein, corresponding to the assumed angles, till the last angle was brought thereon, and so on with respect to the side AK, had it also been crooked. When the sides of a field are curved, the method of reducing them to straight lines is the same as shown in Problem XIV.

It is scarcely necessary to add, that had the fence *abcde* been curved the equalizing line might have been found as in Problem XIV.

227. To trace on the ground with a chain. a triangle, whose three sides are given.—*First.*—When the sides are under 100 feet in length.

Lay off the longest sides first, mark its two ends by pickets: then from one end as centre, and the length of either of the other sides as radius trace an arc upon the ground. With the other end of the fixed line as centre, and the length of the third side as radius, describe a second arc cutting the first arc. the triangle formed by joining the intersection of these arcs with the ends of the base is the one required.

Second.—When the sides are longer than the chain.

In this case a small triangle with its sides less than the length of the chain, but proportionally to the given sides, must be first laid down as in the first case, then two of the sides must be produced to their proper lengths and the line joining their ends will be the third side required.

For instance, suppose a triangle whose sides are 456, 384 and 296 feet respectively, has to be traced.

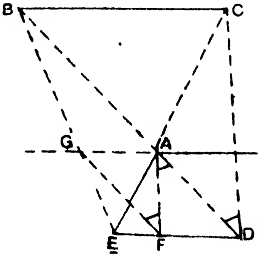
Take $\frac{1}{4}$th part of each of the sides, this gives 114. 96 and 74 feet. Then lay down a line 114 feet long, from one end sweep an arc of 96 feet radius and from the other end an arc of 74 feet radius; mark their intersec tion. Then produce the 114 feet side, and the 96 feet side, to their requir-ed lengths, *i.e.* till they are 456 and 384 feet, respectively; then the line joining their ends will be the third side required, and will be 296 feet long.

228. Through a given point to trace a line parallel to a given line.—*First.*—When the given line is accessible. From the given point A draw any convenient line AB to meet the given line BC. Find the magnitude of the angle ABC, these two lines make with each other: at the given point A, lay off an alternate angle BAG of equal magnitude this will at once give the required parallel line AG.

Second.—When the given line is inaccessible.

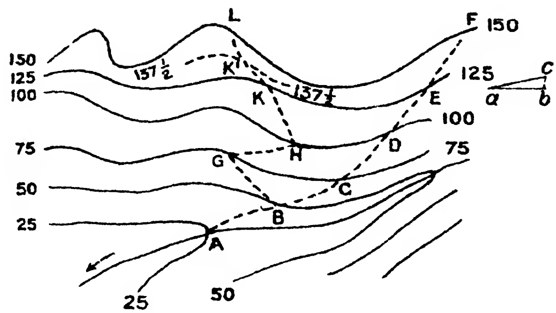
BC is the inaccessible line and A is the given point. Take any points D and E, in the continuations of the lines BA and CA. Find the magnitude of the angle CDA, draw AF parallel to CD, find F in the line DE. Through F draw FG parallel to DA, and find G in the line EB: then the line through G and A is parallel to AB.

Fig. 114.



229. To lay out the direction of road on a hill side at any given slope.

Fig. 115.



Scale—8 inches to 1 mile.

Let the figure represent the contoured plan of a hill-side along which it is required to lay out the direction of a road, rising from the point A to the level 150 at a uniform gradient of 1 in 8. As the interval between the contours is 25 feet, the plan of the road between any two contours will be the base of a right-angled triangle *abc*, in which $ab = 25 \times 8 = 200$ feet. Laying of this distance on the same scale as the map (8 inches to 1 mile) between the successive contours at BCD, etc, the required direction is determined. Should a Zigzag not be objectionable, the road may be made to follow the course BGHKL.

It sometimes happens that the course of the road between two contours close together is not quite clear. In this case an intermediate contour must be interpolated, as $137\frac{1}{2}$ in the figure, and the KK′=100 feet laid off between 125 and $137\frac{1}{2}$, and a further length K′L of 100 feet between $137\frac{1}{2}$ and 150.

As an exercise the student is recommended to the following example:—

Draw four concentric circles, $\frac{1}{4}$-inch apart: diameter of the smallest circle ·75 inch. Assuming these circles to be the contours (50 feet interval) of a conical hill, draw the track of a road ascending from the lowest contour to the summit, at a slope of 1 in 20. Scale—6 inches to 1 mile.

230 To find the boundary of excavation or filling on a contoured plan.—In a problem of this nature, *see* fig. 117, it is necessary to assume that A and B are more or less ruling points or that A and B by trial have been found to give a better gradient, and avoid expensive bridging, protection of permanent way, etc.

To find the boundary of excavation it is necessary first therefore to lay down on the survey the road alignment with the adopted width of road-bed and to show thereon the probable gradient. Next at right angles to the alignment the plan of the contours representing the slope of embanking or cutting—in this case $1\frac{1}{2}$ to 1. The points on the map where these contours intersect the contours of the surveyed map furnish the cutting edge of excavation and the filling edge required. Quantities can be worked out from the above with sufficient accuracy for a preliminary estimate.

231. Setting out gradients.—To set out a gradient it is easier to use a theodolite and having set it up fix on a rod the height of the axis of the telescope, then intersect this height above ground using the following rule. For gradients not steeper than 1 in 10 the angle representing that gradient will be found by the formula $\frac{3438}{n}$ minutes where n is the grade. Thus for a gradient of 1 in 60 the vertical angle would be $\frac{3438}{60} = 57{\cdot}3$ minutes.

APPENDIX.

I. Comparison of the adjustments of the India-Pattern level and that oj a transit theodolite.

(*a*) Ordinary pattern in which when the vertical arc is clamped to a reading the antagonising screws elevate or depress telescope, (that is, the line of sight) without changing the reading ; and (*b*) Cooke, Troughton and Simms' India Office Theodolite where the line of sight is not elevated, but the reading is changed when the antagonistic screws are manipulated.

In both the level and the theodolite the micrometer screw beneath the level and the antagonistic screw of the theodolite may be said to have exactly the same function.

Let us take both instruments and adjust them together, the pill box bubble of the Level being the same as the lower plate levels of the Theodolite.

1. Set up the instrument midway between two staves resting on two pegs, and with the bubble of the level in the centre and with the theodolite clamped at 0·0′·0″ and vertical arc bubble in the centre for both readings on the staves by means of any footscrew directly below the telescope, make the staff readings alike, that is, the heads of the pegs are driven down to the same height above M. S. L.

2. Now, bring the instruments near to one peg so that a staff held on the peg just misses the eyepiece ; roughly level up by the pill box bubble in one case, and the lower plate levels in the other.

Next, remember that the micrometer screw in one instrument functions the same as the antagonistic screw in the other. Place (*i*) the bubble of the level and (*ii*) the vertical arc bubble of the theodolite over one footscrew which should be in a direction of the two pegs. Bring bubbles to centre by one footscrew, correct at right angles by the other two footscrews ; again bring (*i*) and (*ii*) over the one footscrew with the telescope pointing in the same direction as formerly, correct bubble. Next, turn bubble end for end and correct half the error by micrometer (or antagonistic screw) and half by the one footscrew. Repeat till perfect.

3. Bring the staff on the peg up to the eyepiece of the telescope and read through the O. G. end, let the reading be 4·01. If the instrument is in adjustment, the reading should be 4·01 on the other staff, if not, with the level use the micrometer screw to make the collimation line

read 4·01 when the bubble will have left its centre ; bring it back by its own bubble nuts. With the theodolite (already clamped to 0°·0′) *in case* (*a*) use the antagonising screw to elevate or depress the telescope to read 4·01, and correct the bubble by its own bubble nuts, *in case* (*b*) with the slow-motion tangent screw of vertical arc elevate or depress the telescope to read 4·01 and with the antagonising screw make the Vernier read 0°·0′ and correct bubble by its own nuts.

4. When level staves are not available in the case of the theodolite after completing adjustment 2 supra :—Read to an object on Face L, and register the reading, next on Face R, register reading. If the readings are not the same, there is vertical collimation error. In case (*a*) set to the mean reading on the arc by means of the slow-motion screw, and intersect object by the antagonising screw when the vertical bubble will have left its centre ; correct bubble by its own bubble nuts. Case (*b*) set to the mean reading by means of the antagonising screw when the bubble will have left its centre ; correct bubble by its own bubble nuts.

It will be seen by the above that the diaphragm adjustment is unnecessary and can be a Machine fitted fixture in the instrument.

II. Measurement of line over uneven ground :—

Where flat ground does not permit of even an average length base line for an ordinary Engineering Project for a Reservoir or Hydro-Electric Survey but a flat-toped hill exists where a distance of 100 to 200 feet can be measured, a very convenient and accurate method of measuring the line is as follows :—

First reconnoitre a position for the actual base line extremities so that the points at the end of the base line are intervisible and lay out at right angles to the selected base line and at one end of it a line of convenient length. Place a flag at the end of this line. Measure this line very carefully with a steel tape to the second place of decimals of a foot. Proceed to the other end of the base line and having put up your Theodolite there take 20 repeat angles between the base line and the flag. Having now obtained the mean angle subtended by the measured line find from Tables the cotangent of this angle and multiplying this by the distance measured will give the length of the base line.

CURVE TABLES.

TABLE OF NATURAL TANGENTS AND SINES.			TABLE OF CHORDS AND OFF-SETS.									
NATURAL TANGENTS AND SINES			100 FEET CHORDS.						LONG CHORDS TO SAME RADIUS.			
Angle.	Natural tangent and difference for 1 minute.	Natural sine and difference for 1 minute.	Central angle of chord of 100 feet $= a =$ AOB.	Radius $= 50 \operatorname{cosec} \frac{a}{2} =$ AO.	Deflection Distance $= 200 \sin \frac{a}{2} =$ ED $=$ 2TB	Arc of $1° = \frac{2\pi r}{360} = \frac{100\pi \cdot \operatorname{cosec} \frac{a}{2}}{360} = 0{\cdot}8727 \operatorname{cosec} \frac{a}{2}$	Off-set at 25 feet on 100 feet chord $= 25 \tan \frac{3a}{8}$ very nearly $=$ LM $=$ No	Off-set at centre of 100 feet chord $= 50 \tan \frac{a}{4} =$ PQ.	Chord subtending four chords of 100 feet or $4a = 2r \sin 2a = 100 \operatorname{cosec} \frac{a}{2} \sin 2a =$ AG.	Abscissa of 1st 100 foot chord on above $= 100 \cos \frac{3a}{2} =$ AH $=$ GI.	Off-set from last point to end of first chord of $100 = 100 \sin \frac{3a}{2} =$ HB $=$ IP.	Central off-set on chord of $4a = 100 \sin \frac{3a}{2} + 100 \sin \frac{a}{2} =$ KD.
°			° ′									
0	·000000	000000	0 2	171887·34	0·06	3000·007	0·00	0·01	400·00	100·00	0·09	0·12
	·000291	000291	4	85943·67	0·12	1500·003	0·01	0·02	,,	,,	0·17	0·23
1	·017455	017452	6	57295·79	0·17	1000·002	0·02	0·03	399·99	,,	0.26	0·35
	000291	000291	8	42971·84	0·23	750·002	0·02	0·03	,,	,,	0 35	0·47
2	·034921	034899	10	34377·48	0·29	600.001	0·03	0·04	,,	,,	0 44	0·59
	·000291	000291	12	28647·91	0 35	500·002	0·03	0·04	,,	,,	0·52	0·69
3	·052408	052336	14	24550 35	0·41	428·572	0·04	0·05	,,	,,	0 61	0·81
	000292	000290	16	21845·99	0 47	375 002	0·04	0·06	,,	,,	0·70	0·93
4	069927	069756	18	19098·62	0·52	333 333	0·04	0·06	,,	,,	0·79	1·05
	·000298	000290	20	17188·76	0·58	300·001	0·05	0·07	,,	,,	0·87	1·16
5	·087489	087156	22	15626·15	0·64	272·727	0·06	0 08	,,	,,	0·99	1·31
	·000294	000289	24	14323·97	0·70	250·001	0·07	0·69	,,	99·99	1·05	1·40
6	·105104	104528	26	13222·13	0·76	230·770	0 07	0 09	,,	,,	1·13	1 51
	000295	000289	28	12277·75	0·81	214·237	0·07	0·10	399·98	,,	1·22	1·63
7	·122785	121869	30	11459·19	0 87	199·541	0·08	0·11	,,	,,	1 31	1·75
	000298	000288	32	10743·00	0 93	187 501	0 09	0·12	,,	,,	1·40	1·87
8	·140541	139173	34	10111·06	0·99	176 471	0·09	0·12	,,	,,	1·48	1·97
	000297	000288	36	9549·34	1 05	166·667	0·10	0·13	399·97	,,	1·57	2·09
9	·158384	156434	38	9046·75	1·11	157·859	0·10	0·14	,,	,,	1 66	2.21
	·000299	000287	40	8594 41	1·16	150·001	0·11	0·15	,,	99·98	1·75	2·33
10	·176327	173648	42	8185·16	1·22	142·858	0 11	0 15	399·96	,,	1·83	2·44
	000301	000286	44	7813·11	1·28	136·280	0·12	0·16	,,	,,	1·92	2·56
11	·194380	190809	46	7473·42	1·34	130·436	0.12	0·16	,,	,,	2·01	2·68
	000303	000285	48	7162·03	1 40	125·001	0·13	0·17	399·95	,,	2 09	2·79
12	·212557	207912	50	6875·56	1·45	120·001	0·13	0·18	,,	,,	2 18	2·91
	000305	000284	52	6611·11	1·51	115·386	0·14	0·19	399·94	99·97	2·27	3·03
13	·230868	224951	54	6366 26	1·57	111·112	0 14	0·19	,,	,,	2·36	3·15
	·000308	000283	56	6138·90	1 63	107·144	0·15	0·20	,,	,,	2·44	3·25
14	·249328	241922	58	5927·22	1 69	103 450	0·15	0·21	,,	,,	2 53	3·37
	000310	000282	1 0	5729·65	1·75	100·001	0·16	0·22	399 92	,,	2 62	3·49
15	·267949	258819	4	5371·56	1·86	93·752	0·17	0·23	·91	,,	2·79	3 72
	·000313	000280	8	5055·59	1·98	88·237	0·19	0·24	90	,,	2 97	3 95
16	·286745	275637	12	4774·73	2·09	83 335	0·20	0·26	·89	99 95	3 14	4·19
	·000316	000279	16	4523·44	2 21	78·949	0 21	0·28	·88	,,	3·32	4·43
17	·305731	292372	20	4297·28	2 33	75 002	0.22	0·29	·86	99·94	3·49	4·65
	·000320	000278	24	4092·65	2·44	71·430	0.23	0·31	·85	·93	3·66	4·88
18	·324920	309017	28	3906·64	2 56	68·184	0.24	0·32	·83	·93	3·84	5 12
	·000323	000276	32	3736·79	2 68	65·219	0.25	0·33	·82	·92	4·01	5·35
19	·344328	325568	36	3581·10	2·79	62·502	0.26	0·35	·81	·91	4·19	5 59
	000327	000274	40	3437·87	2 91	60·002	0 27	0·36	·79	·90	4·36	5 81
20	·363970	342020	44	3305·65	3·03	57·695	0.28	0·37	·77	·90	4·54	6·05
	000332	000272	48	3183·33	3·14	55·558	0.29	0·39	·75	·89	4·71	6·28
21	·383864	358368	52	3069·50	3 26	53·574	0·30	0·41	·73	·88	4·89	6·52
	·000336	000271	56	2963·72	3·37	51·727	0.31	0 43	·71	·87	5·06	6·75
22	·404026	374607	2 0	2864·93	3·49	49·970	0.32	0·44	·70	·86	5·23	6·98
	·000341	000269	6	2728·52	3·67	47·622	0.34	0·46	·67	·85	5·50	7·33

Angle.	Nat. tan.	Nat Sine.	ACB.	AC.	2TB or ED.	Arc of 1°	LM.	PQ.	AG.	AH.	HB.	KD.
23	·424475	390781	2 12	2604 51	3 84	45 458	0 36	0 48	399 63	99 83	5·76	7·68
	000346	000267	18	2491·29	4·01	43 481	0·38	0 50	·59	82	6 02	8 03
24	·445229	406737	24	2387 50	4 19	41·680	0·40	0·52	·56	·80	6·28	8·37
	000351	000265	30	2292 01	4 36	40·016	0 42	0·55	52	79	6 54	8·72
25	·466308	422618	36	2203·77	4·54	38 465	0 44	0·57	·49	77	6 80	9·07
	000357	000262	42	2122 26	4 71	37·040	0·45	0 57	·44	·75	7·06	9·42
26	·487733	438371	48	2046 18	4 89	35·717	0·46	0·61	·40	73	7 32	9·76
	000363	000260	54	1975·93	5 06	34·487	0·48	0 63	·36	·71	7 58	10·11
27	·509525	453990	3 0	1910 08	5 23	33 337	0 50	0·65	32	69	7·85	10·47
	000370	000258	6	1848·48	5·41	32 262	0 51	0 67	27	67	8 11	10·81
28	·531709	469472	12	1790 73	5 58	31·254	0·52	0 70	22	65	8 37	11·16
	000376	000256	18	1736 48	5 76	30 306	0 54	0·72	·17	63	8 63	11 51
29	·554309	484810	24	1685 42	5 93	29 416	0 56	0 74	·12	·60	8 89	11·86
	000384	000253	30	1637·28	6 11	28 576	0·58	0 76	07	·58	9·15	12·20
30	·577350	500000	36	1591·81	6·28	27 782	0 59	0·79	·01	56	9 41	12 55
	000392	000251	42	1548 80	6·46	27 032	0 61	0 81	398 96	·53	9·67	12 90
31	·600860	515038	48	1508·06	6 63	26 321	0·63	0 83	·90	·51	9·93	13 24
	000400	000248	54	1469·41	6 81	25·646	0 64	0 85	·84	48	10 19	13 59
32	·624869	529919	4 0	1432·69	6 98	25 005	0 65	0 87	·78	45	10 45	13·94
	000409	000245	12	1364·49	7·33	23 815	0·69	0 92	66	·40	10 97	14 63
33	·649407	544639	24	1302·50	7·68	22 783	0·72	0 96	53	34	11·49	15·33
	000418	000243	36	1245 90	8 03	21 745	0 75	1·00	·39	28	12·01	16·02
34	·674509	559193	48	1194·01	8 38	20 835	0·79	1·05	·25	21	12 53	16·72
	000428	000240	5 0	1146·28	8 72	20 006	0 82	1 09	10	·14	13 05	17·41
35	·700208	573576	12	1102 22	9 07	19 237	0 85	1·13	397 94	07	13·57	18·11
	000439	000237	24	1061·43	9·42	18 525	0 88	1·18	78	·00	14·09	18·80
36	·726543	587785	36	1023 55	9 77	17·864	0 92	1 22	·62	98 93	14 61	19·50
	000450	000235	48	988·28	10·12	17·219	0·95	1·27	44	·85	15·13	20·19
37	·753554	601815	6 0	955·37	10 47	16 674	1·98	1·31	26	·77	15.64	20 57
	000462	000231	12	924·58	10 82	16 137	1 01	1·35	08	·69	16·16	21 57
38	·781286	615661	24	895 71	11 16	15 633	1·05	1 40	89	·60	16·68	22·26
	000475	000226	36	868 60	11 51	15·160	1 08	1·44	396 69	·51	17.19	22·95
39	·809784	629320	48	843·08	11 85	14·715	1 11	1 48	·49	42	17 70	23·63
	000489	000224	7 0	819·02	12 21	14 295	1·14	1·53	28	·32	18·22	24·32
40	·839100	642788	12	796·30	12 56	13 899	1 18	1 57	·06	23	18.74	25 02
	000503	000221	24	774 81	12 91	13 523	1 21	1·62	395 84	·13	19·25	25 70
41	·869287	656059	36	754 44	13 26	13 167	1·24	1 67	·61	03	19·77	26 40
	000519	000218	48	735 13	13·60	12·830	1·27	1 70	39	97 92	20 28	27.08
42	·900404	669131	8 0	716 78	13 95	12 510	1·31	1 75	·14	·81	20.79	27·77
	000536	000214	12	699 33	14 30	12 205	1·34	1 78	394·99	·70	21·30	28 45
43	·932515	681998	24	682 70	14 65	11 915	1 38	1 83	·65	·59	21 81	29·13
	000553	000211	36	666 86	15 00	11 639	1·41	1·88	·39	48	22 32	29·82
44	·965689	694658	48	651 73	15 34	11·375	1·44	1 92	·13	·36	22 84	20 51
	000572	000208	9 0	637·27	15·69	11 123	1 47	1·96	393·86	·24	23 34	31·19
45	1·000000	707107	20	614·56	16 27	10·726	1·53	2 04	40	·03	24 19	32·33
	000592	000204	40	593 42	16 85	10·357	1·59	2 41	392·92	96 81	25 04	33·47
46	1 035530	719340	10 0	573 64	17 43	10·013	1·64	2 18	·43	·59	25 88	34·60
	000614	000200	30	546·44	18 30	9 537	1 72	2·29	391·65	·25	27·14	36 29
47	1·072369	731354	11 0	521 67	19·17	9·105	1 80	2·40	390·84	95 88	28·40	37 98
	000637	000197	30	499·06	20·04	8 710	1·89	2 52	·00	50	29 65	39·67
48	1·110613	743145	12 0	478 32	20 91	8 349	1 97	2 62	389·12	11	30·90	41·35
	000663	000193	30	459·28	21·77	8·016	2 05	2·72	388·20	94·69	32·14	43 03
49	1·150368	754710	13 0	441 68	22 64	7 762	2·12	2·84	387 24	·26	33·38	44 70
	000690	000189	30	425·40	23 51	7·425	2 21	2 94	386 25	93 81	34 61	46 36
50	1·191154	766044	14 0	410·28	24 37	7·161	2 30	3·06	385 23	36	35 84	48 03
	000712	000185	30	396·20	25 24	6·915	2·38	3·17	384 16	92 88	37·06	49 68
51	1·234490	777146	15 0	383 06	26·11	6 881	2·47	3·28	384·07	·39	38·27	51·32
	000756	000181	16 0	359·26	27·83	6 270	2·63	3·50	383·76	91 36	40·67	54·59
52	1·279942	788011	17 0	338 27	29 56	5·904	2·79	3·72	378 32	90 26	43 05	57 83
	000785	000177	18 0	319·62	31·29	5 578	2·93	3·94	375·74	89 80	45·40	61 04
53	1·327045	798636	19 0	302·94	33·01	5 287	3·15	4·15	373 02	87·88	47·72	64·22
	000822	000173	20 0	287·94	34·73	5·029	3·29	4 37	370·16	86 60	50·00	67·36

INDEX.

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N.

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